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PROCESS REENGINEERING IN TUBULAR RADIATOR MANUFACTURING

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Abstract*.* *The reengineering of a production line for household heating tubular radiators is described assuming as a reference scenario the facility of one of the leading Italian manufacturers. After a preliminary characterization of products and manufacturing process, a thorough analysis of the production system is carried out in order to highlight current problems and improvement strategies in the light of lean manufacturing concepts. Subsequently, some corrective actions are suggested and their expected effectiveness is assessed also in economic terms. In particular, improvement possibilities have been found in the areas of internal logistics through streamlining of materials flow and layout modifications, as well as process quality increase. Reengineering activities are especially aimed towards layout optimization mainly by resorting to a U-shaped cell-based architecture. Further, the reduction of rework percentage during the assembly phase has been pursued by properly modifying the operations sequence and through integration of a new automated testing station in the production line.*

Keywords: *Process reengineering, Tubular radiator, Manufacturing*

1. INTRODUCTION

In this work a study on reengineering of a manufacturing line for household heating radiators has been presented. As a reference scenario the facility of one of the leading Italian manufacturers of radiators, boilers, tanks and food containers, enjoying a strong presence in the international market, has been considered. Radiators manufacturing is concentrated in a 3500 m^2 plant located in central Italy and includes towel-warmers, single-column and multi-colums product lines. In this paper the production of towel-warmer tubular radiators is specifically addressed. Tubular radiators are an innovative product, experiencing a rapid market share expansion worldwide, with a not yet well-established production technology. Radiator production by the considered manufacturer has steadily grown from 1,000 units in 1992 to 90,000 in 1999, with tubular radiators accounting for 75% of annual revenues. However, in consequence of this rapid increase several problems have arisen, especially in the area internal logistics, giving rise to an overall plant operation deteriorated by flow complexity and delay in responding to customer orders.

With the aim to contribute towards an efficiency increase of the firm a research programme has been undertaken in order to investigate causes of ineffectiveness and find solutions able to remove non value-added activities. Specifically addressed questions are improving the quality level and integrating a new automated inspection-testing station in the existing production process. Having this in mind a critical assessment of the current structure and organization of the entire production process has been carried out (Cochran, 1999). The existence of few and well defined product families immediately led to the adoption of cell manufacturing criteria after comparison with other layout options (Agarwal et al., 1998; Farrington et al., 1998; Billo, 1998) as cell-based production systems often enable a rationalization of material flow in the production system. Cellular manufacturing has been applied successfully in several manufacturing environments and can achieve significant benefits indeed (Block, 1983, Burbridge, 1992). Companies surveyed by Wammerlov et al. (1985) have witnesses a decrease of setup time, WIP inventory and material handling costs, with consistent increase in product quality, material flow, machine and space utilization besides employee morale. In the paper, after a preliminary characterization of the product and the manufacturing process, a thorough analysis of the production system is carried out in order to highlight current problems and improvement strategies in the light of lean manufacturing concepts. Subsequently some corrective actions are defined and evaluated. In particular, different problem-oriented coordinated sub-projects have been started in the areas of internal logistics and material handling through streamlining of materials flow and layout modifications, as well as in a partial redesign of the production process to increase product quality. All of the reengineering activities have been then integrated in a new shop floor organization based on U-shaped cell architecture and operation sequence optimization. In this way both improved material flow and reduced rework percentage may be obtained increasing process performances such as work-in-process (WIP), interoperational handling, product and work environment quality.

2. PRODUCT AND MANUFACTURING PROCESS

Tubular radiator are mainly composed by two vertical collectors with end plugs and a series of horizontal radiant tubes. Such components and the assembly phases are schematically shown in Fig. 1. Tubular radiators manufacturing process requires at first the cutting of collectors and radiant tubes. Radiant tubes are cut to length by two cutting machines working on three shifts and served by a bridge crane. This operation includes tapering of tube extremity in order to ensure proper joining with collectors tubes. Collectors have a non circular cross section and are cut to length resorting to a shearing machine which is shared with the other manufacturing lines. By utilizing a hydraulic punching press collectors side is then punched to create holes enabling the insertion of radiant tubes extremity. Some tubular radiators models for export markets also require stamping of one collector's end resorting to a small press. Further, the majority of radiators models usually undergo pressing of the lateral end part of one of the collectors to create a plane surface enabling to punch a hole for an auxiliary equipment. This operation is carried out by the same stamping press and is followed by manual threading of the punched hole. Collectors and radiants are then assembled on a custom built machine which also flanges the radiants extremities inside the collectors.

Plugs are manually fitted to the collectors ends to seal them and copper paste is applied on all junctions to be brazed. Assembled radiators undergo a brazing treatment in a 30 m long tunnel furnace. At furnace exit radiators are stacked on the shop floor and cooled to ambient temperature by natural convection.

Possible deformations due to uneven thermal expansion are manually corrected. A successive grinding phase removes copper paste drippings and ensures a proper surface finish. This manual operation is quite time consuming and requires skilled operators to avoid subsequent leakage problems. Semiautomatic belt sanding is then carried out in order to remove surface oxidation traces and non uniformities preparing the radiator for subsequent painting. Excluding the phases of plugs fitting and copper paste application, all operations are followed by visual inspection, and a test of dimensional tolerancing is executed on a sampling basis. All radiators instead undergo a final testing carried out by filling the radiator with compressed air and plunging it into a water bath to evidence air leaks. About 15% of tested radiators fail inspection requiring repair which is carried out off-line. The final painting phase is executed in a nearby facility and consists of degreasing, washing, cataphoresis, oven drying and spray epoxy-powder coating. The flow diagram of the entire manufacturing process is depicted in Fig. 2.

Production runs on two shifts, employing 9 operators each, while cutting, funace and the testing/repair stations, being the bottlenecks, are operated also on a third shift employing three to four operators. Average saturation of cutting, assembly, furnace and grinding stations is 95, 97, 99 and 92% respectively, computed on the actual shifts operating hours. According to the original plant layout shown in Fig. 3, the manufacturing facility is currently arranged around three main departments which are tube cutting, common to all radiators models, and two separate areas devoted to the different families of brazed (requiring furnace processing) and single/multi-columns radiators (adopting TIG welding technology). Details of the central area, devoted exclusively to the latter products family, are not shown here as this study focuses on the tubular brazed radiators manufacturing line only. A mixed product/process based layout is adopted having separate flow lines utilized for the two product families where machines are arranged according to the sequence of manufacturing operations, with the two product families sharing some common equipment and the cutting department. A discontinuous lot-based production is adopted with discrete batches of specific radiator models being alternatively processed on the same production line. Production planning is mainly based on a master production schedule (MPS) obtained from demand forecast.

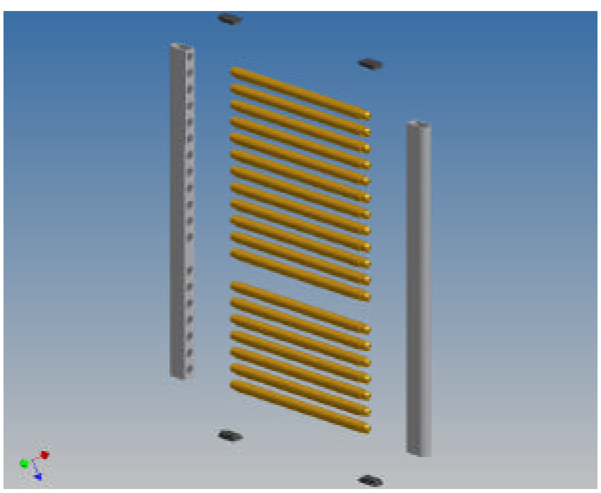


Figure 1 - Scheme of radiator assembly

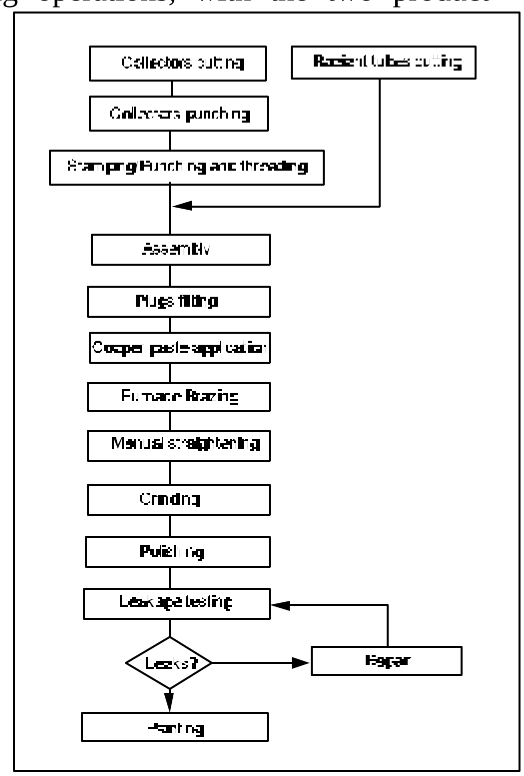


Figure 2 - Production process

However, no operation scheduling is carried out and lot sizes are determined not on the basis of an economic production quantity, but rather from the MPS requirements, and the production planning manager manually issues work orders to the shop floor. A make-to-stock policy is assumed with frequent fulfillment of unplanned single customer orders on make-to-order criteria, following a production advancement report issued weekly by the production planning director. A material requirements planning system (MRP) is utilized for inventory management.

3. CRITICALITY ANALYSIS OF MANUFACTURING PROCESS

A thorough analysis of the production process has been carried out identifying the main weakness in the areas of logistics and process technology.

3.1 Logistic problems

Department location. Cutting machines are far away from assembly station (about 40 meters) resulting in a yearly distance covered to feed assembly machines of over 80 km. However, position of cutting machines is dictated by the bridge crane serving only the upper bay.

Material flows. Due to the position of the stamping and lateral hole punching presses, collectors path from cutting machines to assembly department is winding and a differentiated for the left and right collector (Fig 4), with one collector undergoing punching and stamping and the other punching, extremity pressing and lateral hole punching. The cited stations are located in the cutting department because are shared with the other manufacturing lines.

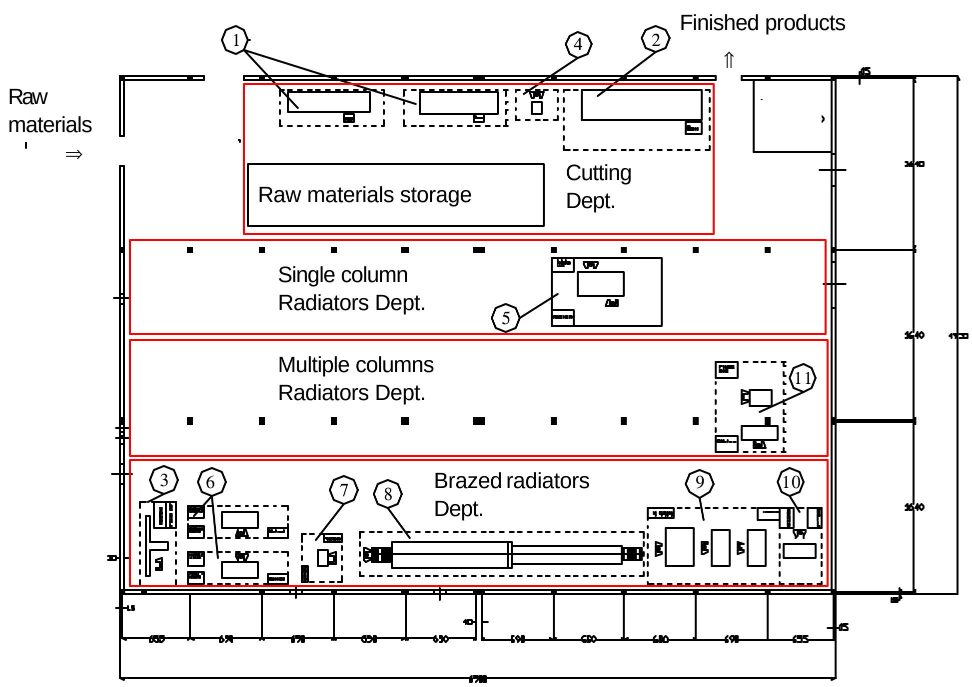
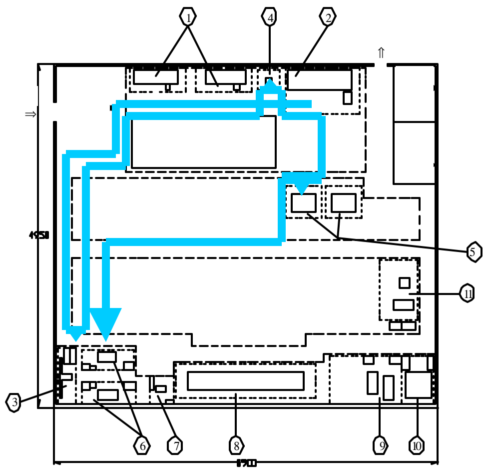
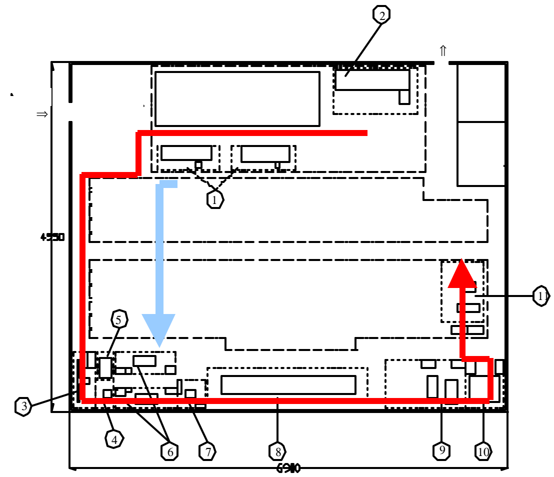


Figure 3 - Current plant layout

1- Radiant cutters, 2- Collectors cutter, 3- Collectors punching, 4- Collectors stamping and pressing, 5- Collector lateral hole punching and threading, 6- Assembly, 7- Plugs fitting and copper paste application, 8- Furnace brazing, 9- Straightening and





Grinding, 10- Polishing, 11- Leakage test.

Figure 4 - Collectors flow in existing layout

Figure 5 - Collectors and radiants flow in the modified layout

Shop floor storage areas. Excessive shop floor areas are utilized as interoperational buffer space also making the material flow difficult. About 80 m^2 of shop floor space in the assembly department are utilized as inventory buffer of radiant and collector tubes interfering with material handling equipment. This area could be utilized to install new machines.

3.2 Technological problems

Cutting process. Imperfect cutting and tapering of radiant tubes extremity occurs due to the fact that cutting machines are operated at or above the maximum cutting velocity range to make up for lacking machine capacity. This causes imperfect joining with collectors and leakage problems. Moreover, a high fault rate occurs causing about 60 monthly hours of on-fault maintenance while required maintenance for all other machines is negligible.

Assembly process. The testing phase reveals excessive defects of the collector-radiants joints. Defects concentrate in the three extremity joints. This is due to the fact that the operation of extremity pressing causes a square cross section of the collector tube end preventing the correct insertion of the internal flanging rod of the assembly machine.

Testing process. Leakage testing is carried out by visual inspection through immersion of assembled radiator in a water bath. Besides causing subsequent corrosion problems, this requires highly skilled operators.

Grinding process. Radiators polishing is carried out by manual grinding. This is a time consuming and costly process. Process times are highly variable and depend from the surface state at the exit of the brazing furnace as well as from operator skill. Currently three parallel grinding stations are utilized employing three operators on three shifts.

4. PROCESS REENGINEERING PROPOSALS

4.1 Logistic problems solutions

Relocation of cutting machines. Within the area served by the bridge crane the two existing cutting machines are moved to the side nearest the assembly department reducing of 15 m the distance between the two departments, with a 38% reduction on annual distance covered (from 80 to 50 km).

Elimination of stamping operation. Current stamping operation is substituted with a simple labeling operation. In this way the existing stamping/pressing machine can be entirely devoted to the collectors end pressing operation.

Relocation of punch/press and threading machines. The existing press machine and a new punching/threading machine are moved directly adjoining the assembly station in order to streamline material flow and achieving a 46% reduction (from 60 to 32 km) in the annual distance covered.

Elimination of radiants and collectors interoperational storage. The existing WIP inventory is moved outside the shop floor, along the facility external side in an existing area currently devoted to locker room.

The shop floor space made available is utilized to house the press and punching/threading machines in proximity of the assembly station.

The resulting improvement in material flow are depicted in Fig. 5.

4.2 Technological problems solutions

Cutting process. A third cutting machine is installed in the cutting department in order to reduce the workload on the two existing cutters thus increasing the machining quality and reducing the likelihood of leakage problems in assembled radiators.

Modification of process sequence. A new press and a new punching/threading machine able to operate on already assembled radiators are installed after the assembly station. A 35% reduction of inspection testing failures is expected.

Modification of the testing station. A new automatic test bench has been developed at the University of L'Aquila which does not require water immersion to perform the leakage test. Two such benches in parallel can substitute the three different existing water testing stations serving the three manufacturing lines.

The net workforce reduction is equivalent to one operator on three shifts.

Automatization of grinding/polishing operations. An automatic grinding/polishing station served by a robot may reduce the required workforce by three operators on each of the three shifts. Such a station has been already installed.

5. LAYOUT OPTIMIZATION

The previously described measures are to be intended as low-cost and rapidly implementable solutions to specific inefficiency problems. However, a radical layout revision may be instead attempted in order to optimize the facility as far as the material flow and work organization are concerned. A further improvement may be in fact pursued by adopting a "U-shaped" cell layout as show in figure 6. This greatly streamlines material flows especially with reference to raw materials input and finished products output from the shop floor which is concentrated on the same side of the facility, reducing interferences with the other two manufacturing lines. The only remaining interference lies in the output flow from the leftmost cell to the finished goods storage area at the right upper corner of the facility, which is a minor problem due to the low material flow interested.

Furthermore, the final layout with parallel U cells allows for unchanged positions of furnace and cutting department, enhancing also flexibility in operators assignment inside each cell. In this way high performances may be reached maintaining at the same time low investment costs.

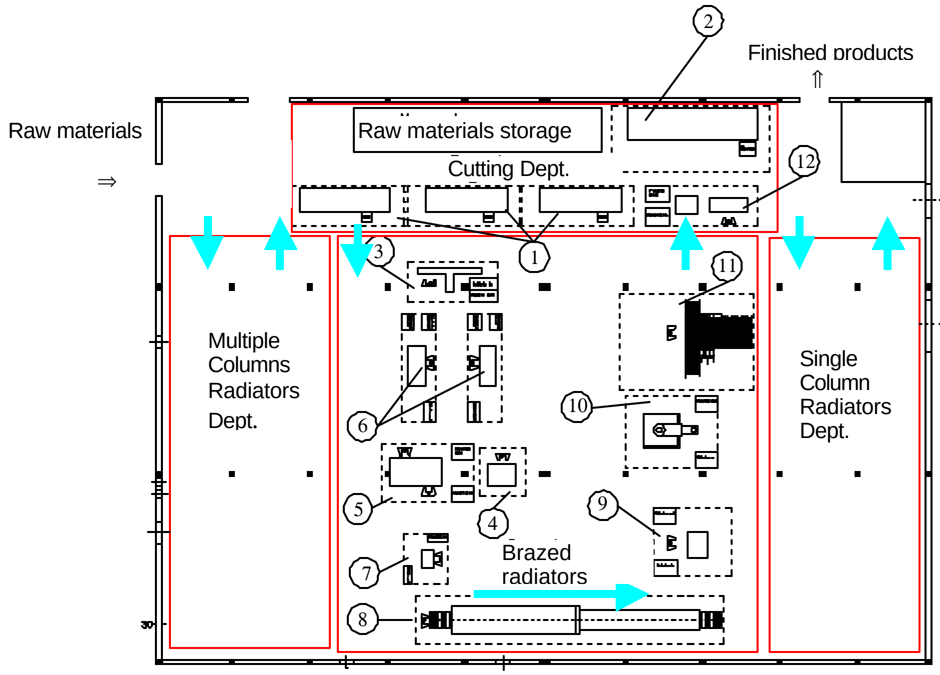


Figure 6 - New U-shaped layout.

6. COST-BENEFITS ANALYSIS

Main benefits of the proposed reenginering process may be summarized as follows:

- Material flow streamlining and reduction of the overall yearly distance covered for material handling (35% and 46% reductions respectively for radiants and collectors) with a 40% saving on transportation energy expenses. Adopting the U layout transportation costs would be virtually eliminated.
- Improved work environment and reduced risk of accidents.
- Reduction of reworks by about 35% thanks to improved process quality leading to savings on operating labor (estimated in about 900 man-hours yearly) and scrap reduction. Reduction of rework rate also increases throughput.
- Savings in operating costs.

The expected costs and savings from the proposed measures are resumed in Table 1. Based on the estimated values of required capital investments and operating labor savings a pay back time of about 2 years results.

Table 1 - Process reengineering cost items and savings

	INVESTMENTS (US$)
Layout modifications and civil works	30.000
New cutting machine	75.000
New labeling machine	5.000
New press and punching/threading machine able to operate on assembled radiators	50.000
New testing station (two machines)	55.000
Automated grinding/polishing station	300.000
TOTAL	**515.000**
	SAVINGS (US$/year)
Testing/Repair department labor	100.000
Grinding/Polishing labor	150.000
TOTAL	**250.000**

7. CONCLUSIONS

The problem of process reengineering in a tubular radiators manufacturing facility has been examined developing a set of corrective measures resulting in a strong streamlining and an effective rationalization of the production process. The suggested actions involve both layout redesign and modification in the technological process which can be implemented with moderate investments obtaining significants advancements in terms of material flow, bottleneck avoidance, quality improvement besides relevant savings in labor costs. The proposed reengineering activities respect also an environmental conscious manufacturing approach reducing the energy and materials content in the product, improving as well the working conditions.

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