TECHNICAL AND ECONOMIC VERIFICATION OF THE CONVENIENCE IN REENGINEERING A PRODUCTION LINE USING SIMULATION TECHNIQUES

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ABSTRACT

The work shows some proposals for achieving the production flow optimization of an engineering company production lines, operating in the automotive sector. Moving from the analysis of the actual line production efficiency, either by simulative techniques, either by technical-economic analyses, some improvement actions have been proposed and validated. The results obtained, referring to production capacity and equipment state, have point out that the proposed solution permits both a productive flow optimisation and a productiveness increase.

Keywords: modelling, validation, productiveness, bottle neck

1. CASE STUDY

The company is a leading global supplier of bearings, seals, mechatronics, lubrication systems and services which include technical support, maintenance and reliability services, engineering consulting and training.

It is a global company, established in Europe, North and Latin America, Asia and Africa. Today, it is represented in more than 130 countries. The company has more than 100 manufacturing sites and also sales companies supported by about 15,000 distributor locations; a widely used e-business marketplace and an efficient global distribution system.

The company works mainly through three business areas: Strategic Industries and Regional Sales and Service, servicing industrial original equipment manufacturers and aftermarket customers respectively, and Automotive, servicing automotive producers and aftermarket customers. It operates in around 40 customer segments, whereof examples include cars and light trucks, wind energy, railway, machine tool, medical, food and beverage and paper industries.

Technical development, quality and marketing have been strongly in focus since the beginning. The Group's efforts in research and development have resulted in numerous innovations, forming bases for new standards, products and solutions in the bearing world. Due to a reorganization of the establishments in Europe, some plants have started producing a new type of ball bearing, such as the studied one.

The bearing actual production capacity was much lower than the theoretical. It has been necessary, therefore, the identification of production process improvements, to be adopted quickly and with no waste of efforts. The use of simulation techniques allowed obtaining the above goals.

2. DESCRIPTION OF THE LINE

Inside the considered plant, the production is organized by production channels, ie small units including all operations, machines and resources required for bearing production, starting from raw materials or semi-finished products to obtain the finished product.

The whole manufacturing process consists of six main phases: Moulding, Turning, Heat treatment, Facing, Grinding, Assembly.

The object of the study, channel 9, on which it carries out grinding, lapping and assembly, consists of two branches developing longitudinally and parallel to each other to meet in assembly (Figure 1).

On the left line grinding machines and monitoring devices for inner ring are located, while, on the right line, the machines for outer ring processing are placed.

At the top of the line, all the rings are subjected to a 100% dimensional control through head-line control devices, in order to verify the actual match of measurement and processing schedule.

On the inner ring the following operations are performed:

- *facing*,
- *face grinding* (material is removed from the faces of the ring),

- *throat and flange grinding*,
- *hole grinding*,
- *throat lapping* (carried out to achieve high surface finish).

Figure 1: Channel 9: grinding and lapping

For the latter operation, they don't use grinding wheels, but shaped and with a decreasing particle size stones.

On the outer ring, instead, throat grinding and lapping are performed. Following lapping, all the rings pass inside demagnetizers with the function of removing dirt and metal particles residues from the rings.

Subsequently, they pass through special washing machines, in order to eliminate any further processing residues, harmful for the bearing.

IR and OR rings, previously machined on the grinding lines, are placed in the assembly line to be attached with other components characterizing the ended bearing (cages, spheres, shield, etc.).

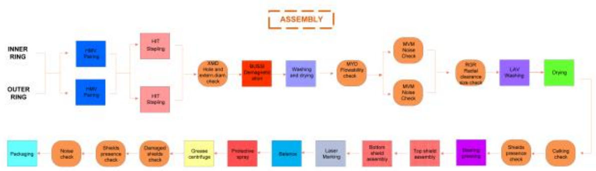

Figure 2: Channel 9: assembly

The operations on the branch assembly are the following (Figure 2):

- *pairing*, by which inner ring, outer ring and spheres are matched using machines able to realize radial clearance customer requirements;
- *stapling*, ie metal or plastic cages assembly;
- *hole and outer diameter size check*;
- *flowability, noise and radial clearance size check*;
- *washing and drying operations*;
- *bearing greasing*;
- *marking*;
- *amount of inserted grease check*;
- *sprinkling with a protective spray*;
- *packaging*.

3. LINE EFFICIENCY ANALYSIS

Observations in order to assess the efficiency of the line have been carried out. In particular, it has been observed the trend of the grinding and lapping branches production flow.

The theoretical production of the line is 2100 pieces/hour.

In practice, this value is not reachable, even considering the ideal time machine.

There are two machines, indeed, SHG and Denison, with maximum theoretical production capacity, respectively, of 1831 and 1800 pcs/h, because, at higher speeds, they would produce rings with sizes outside required tolerances and, therefore, by discard.

Besides, it has been noted as OR branch was faster than IR. It has been found, in fact, that the sum of the working average time on IR was greater than OR of more than 2 seconds, both considering measured cycle time both the ideal ones.

The problem is represented by hold grinding machine (SHG), that is the bottleneck of the line.

The presence of these differences on processing time has important issues about the whole process upstream, with birth of queues and stops along the line.

These are difficult to dispose of because of a substantial problem involving continuous accumulation of OR before assembly line and IR before SHG machine.

Our analysis has permitted to esteem the real line productive capacity and efficiency.

Table 1: Production capacity and line efficiency

	Channel 9
Gross production (expected)	**2100 units/hour**
Actual mean production (standard conditions)	**1220 units/hour**
Productive loss	**-880 units/hour**
Efficiency (%)	**58,1 %**

4. PROCESS FLOW OPTIMIZATION

Analyzing the data, it has come to define measures to increase production capacity.

Since the fully automated line, it's not very useful to focus on the operators. However, the work team experience is essential both to solve occurring problems and for operations speed carrying out such as tool change or machinery cleaning.

Nor it is possible to think of reversing some processes, which must necessarily be carried out according to a defined sequence.

The possible proposed actions, therefore, are the following:

1. IR interoperational buffer introduction

Introduction at the end of IR branch, of a buffer containing inner rings ground and lapped on another line working the same type of ring and in excess.

This operation would compensate for the deficiency due to the slow processing of this part of the line.

2. Adding a machine SHG

An alternative is the addition of a fourth machine SHG, the bottle neck of the line.

Assuming the new machine cycle time the average of the analogous SHG cycle times, this operation would increase the daily production capacity of about 2400 pieces and would reduce the production speed difference between OR and IR branches, although still OR processing faster.

3. SHG time machine reduction

It’s the most practical alternative, since it would change less the line.

Reducing to 6 seconds the cycle time for all three SHG, measured time of one of the three machines, there would be a production capacity increase.

To achieve that, it should understand the causes that make:

- the three machines processing times variables between them;
- cycle times higher than theoretical time machine.

As regards the first point, it’s important that SHG machines are slightly different from each other, in fact one of them is older than the others.

Furthermore, even if the initial setting is the same for the three machines, there are parameters only adjustable manually by the operator.

The operator also intervenes changing working parameters when he detects problems such as high amounts of waste.

The hole diameter size, moreover, are slightly different between the pieces, always within the tolerance range (10 µm).

Regarding the second point, the reasons may be different.

- the material quality is very important; it was noticed, in fact, that thermally treated rings within the plant are qualitatively better than external suppliers rings. Therefore they can be processed at higher speeds without causing many rejects or blocks machine.
- Sometimes the SHG are purposely slowed down by operators, for example when following assembly line is blocked.

Therefore, the operation that could be made is to redesign three machines processing cycle, optimizing it, ie to re-examine the values of the process parameters, the type of tool and the combination of the two, in order to obtain a reliable processing as much as possible. The three machines are similar, but not identical, then the set process parameters, which are the same, could be optimized only for one of them.

Secondly, should be adopted actions, such as a machine internal control system, aimed at minimizing subjectivity of operations.

5. VERIFICATION THROUGH A SIMULATION MODEL

To value the technical and economic suitability of the proposed interventions, it has been designed, using a dedicated software, a process model.

The fullness and the truthfulness of the simulation model have been tested in different conditions and on long simulation time periods.

The productiveness data has been obtained referring to a continuum operative period of 48 hours (a total production of 76,665 units – 1600 pcs/h), to guarantee the simulation stabilisation and reliability.

The results achieved by the model were, in terms of production trend, fully comparable with the ideal ones.

Time analysis shows how the bottle neck of the line is represented by SHG, which can produce a maximum of 1674 pcs/h. This value is slightly higher than the one obtained from the model, since the latter considers set-up time, inevitably present.

The simulation model results have been compared to real data, validating the designed simulative analysis.

The problems, coming out from the simulation model, are the same as those noticed during the process observation. Particularly evident are the following aspects:

- material accumulation on OR branch, after a short time. The OR branch is much faster than IR one, so the OR buffer, placed before coupling machine HMV, and dedicated machines buffers fill chain up to create a partial block of the branch, which restarts each time a piece from IR branch comes (Fig. 3).

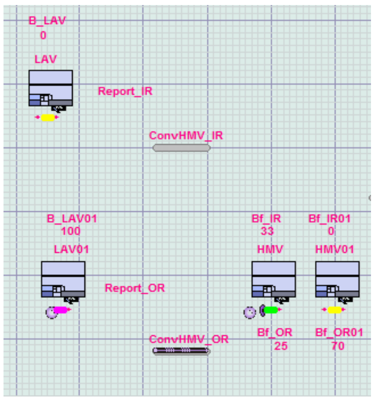

Figure 1 – Accumulation in the OR buffer placed before coupling machine HMV

- sliding bearing on the assembly line goes perfectly, buffers are empty.
- concerning to IR branch, the problem is on SHG (Fig. 4): in correspondence of these machines, the line has a large quantity of pieces into dedicated buffers and on conveyor belts, because SHG are unable to dispose of incoming pieces slowing down the entire process.

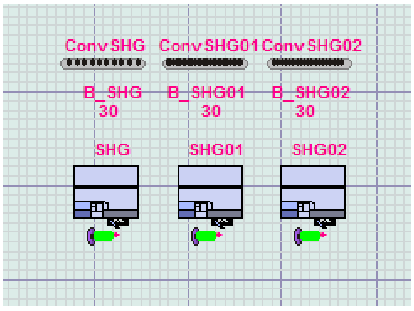

Figure 2 – Accumulation at the SHG

This feature is also known by the machines work data obtainable by the simulation model and shown below. The SHG (Fig. 5), in fact, works almost all the time, having always available workpieces.

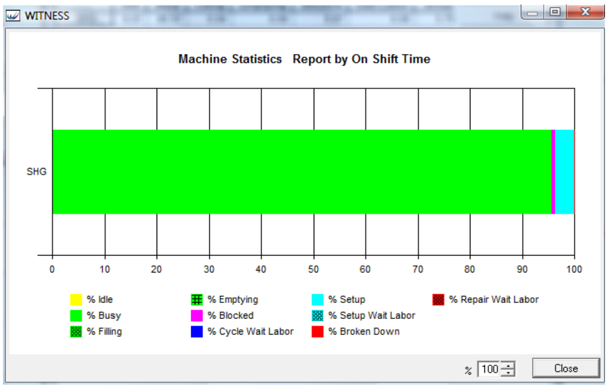

Figure 3 - SHG field data after 24 hours of production

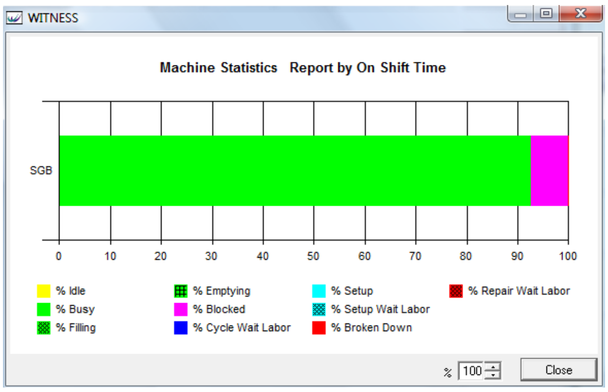

Figure 4 - SGB field data after 24 hours of production

Also the SGB (Fig. 6) runs continuously, although it is blocked for a certain period of time since, otherwise, being faster than SHG, it would produce an excessive number of pieces.

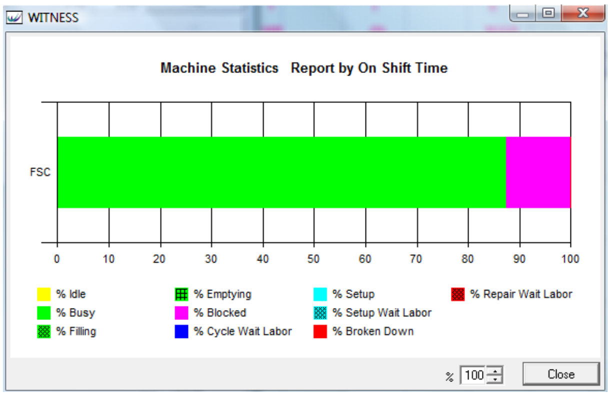

Figure 5 – First FSC field data after 24 hours of production

The FSC percentage blocking (Fig. 7), instead, is linked to the higher processing speed of the branch OR than IR, so it must be stopped for a period to adapt to the production on the other branch.

It's also noted from work data that the second MVM (Fig. 8), on the assembly line, is, for most of the time, on hold of work, so underutilized.

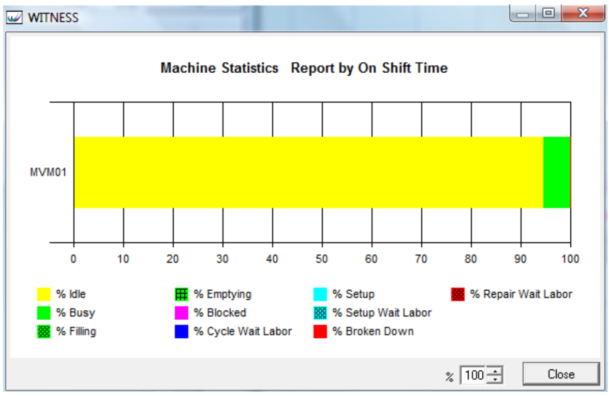

Figure 6 - MVM2 field data after 24 hours of production

The simulation model also confirms proposed changes validity: all three alternatives would lead to increase production capacity.

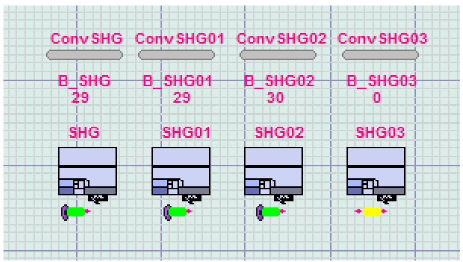

Figure. 7 – Addition of a forth SHG: situation after 24 hours on IR grinding branch

For example, figure 9 shows how a fourth SHG allows to have less accumulation in the buffers and on the conveyor belts before SHG, even after 24 hours, showing how, unlike before, these machines are able to dispose of the production.

6. TECHNICAL AND ECONOMIC ANALYSIS OF THE PROPOSED MODEL

The simulation time relative to the proposed model refers to 48 hours of continuum line activity. The data coming out from the changed model, shows a great increase both in hourly production and machines saturation.

1. Inserting a buffer of 1000 pieces per day, would increase the daily production capacity of about 1000 pieces, actually 745 whereas the actual production and model production differ by a certain percentage. This happens because there are other influential parameters, such as blocks machine, for example for faults, and waste.
2. The addition of a fourth machine SHG with a cycle time assumed as the average of the similar SHG cycle times, increases the theoretical daily production capacity of about 3200 pieces (actual 2400 pieces) and reduces the production speed difference between OR and IR branches, while remaining OR machining faster.
3. The last alternative, finally, would carry an actual production increase of about 1950 pieces.

Subsequently, the new model has been economically validated.

1. The interoperational buffer introduction would increase slightly the efficiency but, at the same time, would cost just as little, ie as the cost of the buffer, which is assumed of 1000 €.
2. Relatively to the second solution, it is considered:

- The cost of the machine of € 500,000,
- The payback period of 10 years,
- The selling price of the bearing of 1 €,
- 220 working days per year, with an increase in annual production amounted to 529,540 pieces;

and it is assumed that the additional produced quantity is actually sold.

Under these conditions, assuming different values of gain from the sale of a bearing and interest rate of 6%, with *discounted payback* technique of valuation of investments, it will get different payback times (Fig. 10 a,b).

Gains 0,12 €/bearing

Years	Net Cash Flow	Interest factors at 6%	Net present flow	Progressive Cash Flow
0	-500.000 €		-500.000 €	-500.000 €
1	63.545 €	0,94	59.948 €	-440.052 €
2	63.545 €	0,89	56.555 €	-383.497 €
3	63.545 €	0,84	53.353 €	-330.144 €
4	63.545 €	0,79	50.333 €	-279.811 €
5	63.545 €	0,75	47.484 €	-232.326 €
6	63.545 €	0,70	44.797 €	-187.530 €
7	63.545 €	0,67	42.261 €	-145.269 €
8	63.545 €	0,63	39.869 €	-105.400 €
9	63.545 €	0,59	37.612 €	-67.788 €
10	63.545 €	0,56	35.483 €	-32.305 €

Payback period: > 10 years

Gains 0,13 €/bearing

Years	Net Cash Flow	Interest factors at 6%	Net present flow	Progressive Cash Flow
0	-500.000 €		-500.000 €	-500.000 €
1	68.840 €	0,94	64.944 €	-435.056 €
2	68.840 €	0,89	61.268 €	-373.789 €
3	68.840 €	0,84	57.800 €	-315.989 €
4	68.840 €	0,79	54.528 €	-261.461 €
5	68.840 €	0,75	51.441 €	-210.020 €
6	68.840 €	0,70	48.530 €	-161.490 €
7	68.840 €	0,67	45.783 €	-115.708 €
8	68.840 €	0,63	43.191 €	-72.517 €
9	68.840 €	0,59	40.746 €	-31.770 €
10	68.840 €	0,56	38.440 €	6.670 €

Payback period: from 9 to 10 years

Figure 8 a) - Payback discounted method

Gains 0,14 €/bearing

Years	Net Cash Flow	Interest factors at 6%	Net present flow	Progressive Cash Flow
0	-500.000 €		-500.000 €	-500.000 €
1	74.136 €	0,94	69.939 €	-430.061 €
2	74.136 €	0,89	65.980 €	-364.080 €
3	74.136 €	0,84	62.246 €	-301.835 €
4	74.136 €	0,79	58.722 €	-243.112 €
5	74.136 €	0,75	55.398 €	-187.714 €
6	74.136 €	0,70	52.263 €	-135.451 €
7	74.136 €	0,67	49.304 €	-86.147 €
8	74.136 €	0,63	46.514 €	-39.633 €
9	74.136 €	0,59	43.881 €	4.248 €
10	74.136 €	0,56	41.397 €	45.644 €

Payback period: from 8 to 9 years

Gains 0,15 €/bearing

Years	Net Cash Flow	Interest factors at 6%	Net present flow	Progressive Cash Flow
0	-500.000 €		-500.000 €	-500.000 €
1	79.431 €	0,94	74.935 €	-425.065 €
2	79.431 €	0,89	70.693 €	-354.372 €
3	79.431 €	0,84	66.692 €	-287.680 €
4	79.431 €	0,79	62.917 €	-224.763 €
5	79.431 €	0,75	59.355 €	-165.408 €
6	79.431 €	0,70	55.996 €	-109.412 €
7	79.431 €	0,67	52.826 €	-56.586 €
8	79.431 €	0,63	49.836 €	-6.750 €
9	79.431 €	0,59	47.015 €	40.265 €
10	79.431 €	0,56	44.354 €	84.619 €

Payback period: from 8 to 9 years

Figure 90 b) - Payback discounted method

Increasing even one euro cent profit from the sale of a bearing, it can see as the recovery time decreases and simultaneously the total gain increases – NPV Method (fig. 11).

Gains 0,12 €/bearing

Years	Net Cash Flow	Interest factors at 6%	Investment S_0	Discounted cash flow R
0	-500.000 €		-500.000 €	
1	63.545 €	0,94		59.948 €
2	63.545 €	0,89		56.555 €
3	63.545 €	0,84		53.353 €
4	63.545 €	0,79		50.333 €
5	63.545 €	0,75		47.484 €
6	63.545 €	0,70		44.797 €
7	63.545 €	0,67		42.261 €
8	63.545 €	0,63		39.869 €
9	63.545 €	0,59		37.612 €
10	63.545 €	0,56		35.483 €
			PV	467.695 €
			NPV	-32.305 €

Gains 0,13 €/bearing

Years	Net Cash Flow	Interest factors at 6%	Investment S_0	Discounted cash flow R
0	-500.000 €		-500.000 €	
1	68.840 €	0,94		64.944 €
2	68.840 €	0,89		61.268 €
3	68.840 €	0,84		57.800 €
4	68.840 €	0,79		54.528 €
5	68.840 €	0,75		51.441 €
6	68.840 €	0,70		48.530 €
7	68.840 €	0,67		45.783 €
8	68.840 €	0,63		43.191 €
9	68.840 €	0,59		40.746 €
10	68.840 €	0,56		38.440 €
			PV	506.670 €
			NPV	6.670 €

Gains 0,14 €/bearing

Years	Net Cash Flow	Interest factors at 6%	Investment S_0	Discounted cash flow R
0	-500.000 €		-500.000 €	
1	74.136 €	0,94		69.939 €
2	74.136 €	0,89		65.980 €
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7	74.136 €	0,67		49.304 €
8	74.136 €	0,63		46.514 €
9	74.136 €	0,59		43.881 €
10	74.136 €	0,56		41.397 €
			PV	545.644 €
			NPV	45.644 €

Gains 0,15 €/bearing

Years	Net Cash Flow	Interest factors at 6%	Investment S_0	Discounted cash flow R
0	-500.000 €		-500.000 €	
1	79.431 €	0,94		74.935 €
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8	79.431 €	0,63		49.836 €
9	79.431 €	0,59		47.015 €
10	79.431 €	0,56		44.354 €
			PV	584.619 €
			NPV	84.619 €

Figure 11 - Net present value method

The costs associated with the production capacity increase by performing a reduction of SHG times to measured time for one of the three machines (6 seconds), are not very high. Annually, there is an increase of cost of about € 2260 due to increased consumption of grinding wheels compared to an increase of gain from bearings sale of approximately €

51,300 (assuming earnings per bearing of € 0.12). This is true assuming the tool wear does not increase by reducing to these values the cycle time and, therefore, the diamond coating interval should be not reduced.

7. CONCLUSIONS

In this paper a production process re-engineering methodology is proposed.

The planning process has been supported by techno-economic analysis, using simulation techniques. The developed procedure has enabled the company to achieve significant benefits.

The advantages obtained thanks to the application of simulation techniques to the bearing production process, include:

- increase in the productive efficiency;
- increase in the machines saturation;
- reduction in the bottle necks.

The first solution is characterized by a very low realization costs, 1000 €, compared to a production capacity increase by 2.5% (about 750 pcs/day), but it requires continuous availability of components from another production line. The second alternative is the most expensive to implement, due to the machine cost (500,000 €), but it allows the production capacity increase higher, equal to 8.2% (about 2400 pcs/day).

The third option would be certainly more convenient, since it does not involve changes to the production channel and, at the same time, it would lead to an efficiency increase slightly less than adding a fourth SHG machine (6.6%, about 1950 pcs/day). The cost would be definitely lower, about 2250 €, but it should study how actually to be able to implement this solution.

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