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SMART SUSTAINABILITY OPTIMIZATION (SSO) IN AUTOMOTIVE ENGINE COMPONENTS MANUFACTURING LINE: WEB-BASED TRIPLE-BOTTOM LINE OPTIMIZATION FACILITY (PROPTIM)

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Abstract. *Long-term environmental sustainability in the manufacturing environment requires that artifacts, materials, systems and processes be designed to minimize energy and waste and to maximize reuse and utility. The sustainability Optimization task is typically an attempt to compromise conflicting goals, such as: Minimize negative impact on environment, maximize quality, minimize cost, maximize profit, minimize time, etc. and be aligned with the Triple Bottom Line (TBL) guidelines. In this paper a specially developed Smart Sustainability Optimization (SSO) tool in the context of the FoFdation project is applied to an automotive industry case. The test use case is a factory shop floor with up to 30 machine tools that should be optimized for sustainability using several energy, social and emissions key performance indicators. The tool selects and proposes potential further-optimized production schedules based on the currently working/available schedule, the sustainability evaluations, and the desired manufacturing goals.*

1 INTRODUCTION

The FoFdation project

The EC project "Foundation for the Factory of the Future (FoFdation) project [1] proposes a straightforward approach for achieving sustainability goals: by leveraging an existing MES functionality to manage raw materials and resources. Specifically, a new generation of MES is being developed for supervising productivity and sustainability indicators to meet the triple-bottom line corporate objectives. This concept proposes an extension of MES towards sustainability monitoring and control. Today, the sustainability strategy of many manufacturing companies focuses on the Triple Bottom Line integrating economic, environmental and social goals. In order to give a holistic vision of the manufacturing operations in a company production-to-enterprise, integration including extension to sustainability control will be achieved. Moreover, the act of automating a manufacturing process to increase efficiency reduces cycle times, reduces human error and potential re-work, increases visibility of material flow and optimizes scheduling – all driven by economics. At the same time, these changes reduce energy expenditures, reduce labor – by reducing the use of gasoline consumption and capital expenditures such as office space and the energy required to power and heat them – and minimize scrap material, all facets of environmental stewardship.

The data from these automation efforts has been traditionally used to make decisions on what to produce and when to produce it. But that data can also be used to make further cost reduction decisions, such as shifting production schedules to accommodate running in off-peak hours and potentially selling surplus energy back to the grid, forwarding the latest trend: corporate responsibility through the right decision supported by an overall dashboard for Smart Factory Integration. This new generation of MES developed in the project incorporates several dedicated modules to address the above objectives and requirements. This enhanced MES (or Smart MES) will be able to optimize its traditional results for sustainability with the use of specialized tool such as the Smart Sustainability Optimizer (SSO) [2]. For a detailed description of the SSO algorithm, please refer to the authors' paper [3].

2 SSO AUTOMOTIVE USE CASE DESCRIPTION

The Smart Sustainability Optimizer (SSO) software tool will be demonstrated using a realistic manufacturing example of an automotive plant shop floor consisting of 8 operation points (OPs) and 30 machines (figure 4).

Its focus lays on the total sustainability in production (energy, social, emissions, etc.) for:

- Optimized scheduling: i.e. producing optimized work-order schedules for the Smart MES.
- Optimized machine operation definition: further to the direct Sustainability Approach on fixed Shop Floor machine configuration, the next step towards optimized sustainable production is to consider the potential for dynamic flexibility, for example to reassess the number of active machines per operations group and/or to reassign certain machines to Operation Groups other than those initially assigned to, depending on the number, type and deadlines of work-orders. The SSO will also focus on handling unforeseen problems such as bottlenecks due to machine breakdown, etc.

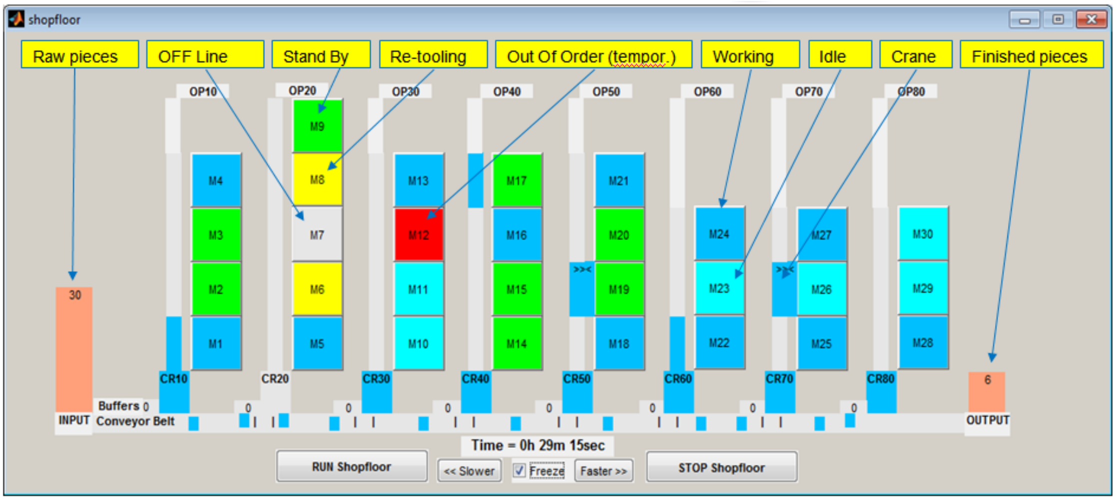

Figure 1 – A full generalized example with 8 OPs and 30 Machines

3 SSO AUTOMOTIVE USE CASE SCENARIOS

In order to demonstrate the functionality and capabilities of SSO a number of use case scenarios is prepared as shown in the following table:

1. Default (Current Case)	A Reference Case representing the current typical situation (5000 units/week) as close as possible to reality.
2. Full Rate (Theoretical MAX)	An ideally fast production using all capabilities, the highest feed rate and additional personnel where required.
3. Optimal TBL Sustainability	Based on the Default Case but with the Capability to switch the machines to Stand-By and to apply various Work Shift Patterns.
4. Variable Production (TBL including machine shutdowns)	4a. Reduced production Cases with the Capability toadjust the production speed. 4b. Increased production Cases with the Capability to adjust the feed rate and the number of workers.

Table 1 - Use case scenarios

3.1. Default (Current Case)

A Reference Case representing the current typical situation (A units/week) as close as possible to reality. The work-week is a 5-day week where each day is comprised of three consecutive shifts (morning, afternoon and night) including a 30-minute break in the middle of each shift. Machines are not set to standby between machinings. For comparison with the other cases, lower TBL sustainability index is better.

ECONOMIC KPI - Availability	93.7%
ECONOMIC KPI - Performance Efficiency	32%
ECONOMIC KPI - Scrap ratio	5% same for all
ECONOMIC KPI - Quality	95% same for all
ENVIRONMENTAL KPI - Energy consumption	100%
ENVIRONMENTAL KPI - Energy efficiency	1
ENVIRONMENTAL KPI - Saved energy	0%
ENVIRONMENTAL KPI - CO_2 direct	100%
ENVIRONMENTAL KPI - CO_2 indirect	100%
SOCIAL KPI - Injury rates vs work patterns	0.49 / year / 100 employees
SOCIAL KPI - Lost days / absenteeism	0.44 / year/100 employees
TBL SUSTAINABILITY INDEX	0.619

Table 2 – KPI and TBL sustainability index results for the default case

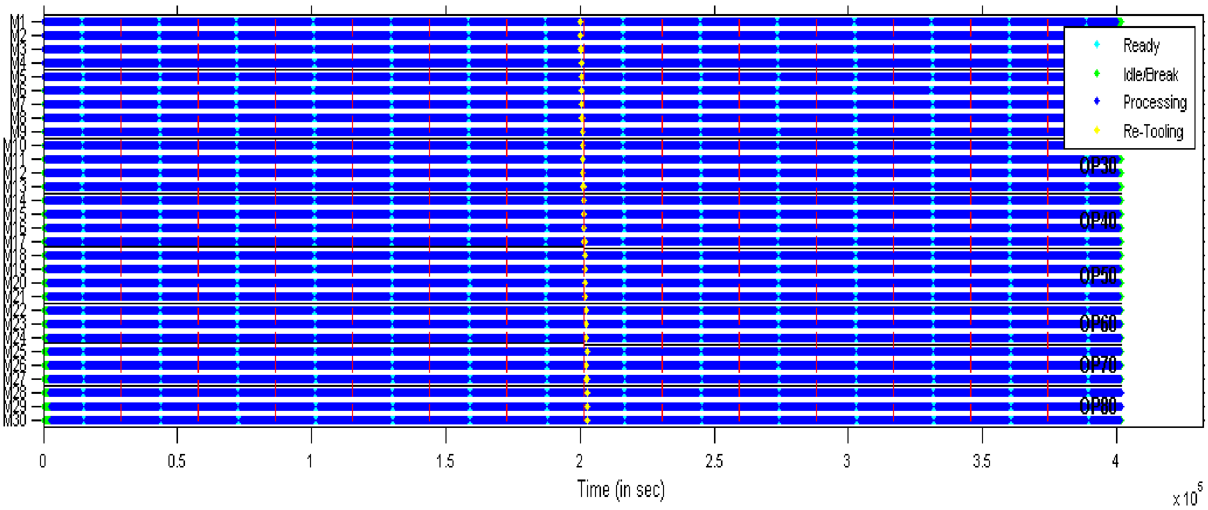

Figure 2 – Full week production pattern for the default case

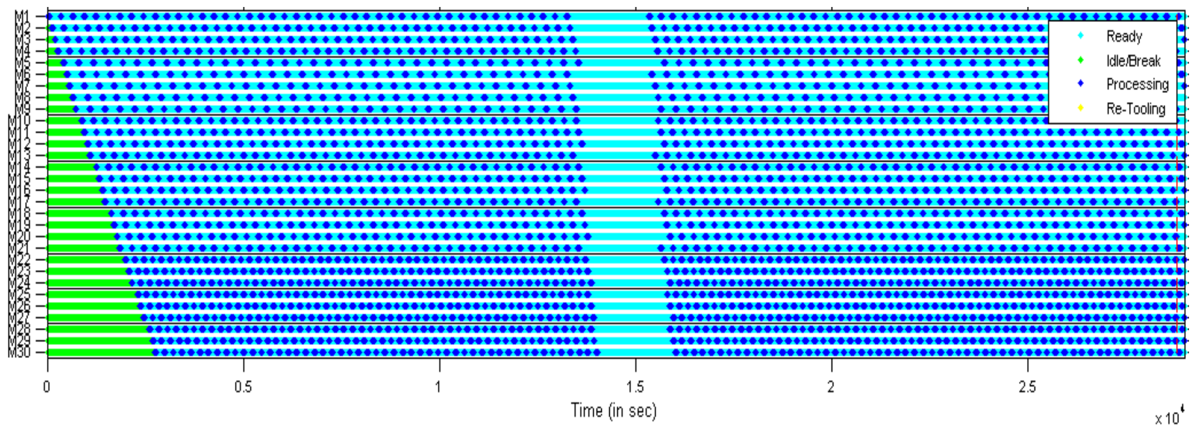

Figure 3 – Full shift production pattern for the default case

3.2. Full Rate (Theoretical MAX)

An ideally fast production using all capabilities, the highest feed rate (approximately three times A units of scenario 3.1) and additional personnel where required. Machines are not set to standby between machinings. This case is not expected to produce a better TBL sustainability index compared to the default case, it is included demonstrate the KPI values at the theoretical full rate.

ECONOMIC KPI - Availability	93.7%
ECONOMIC KPI - Performance Efficiency	68%
ENVIRONMENTAL KPI - Energy consumption	107% of case 3.1
ENVIRONMENTAL KPI - Energy efficiency	1
ENVIRONMENTAL KPI - Saved energy	0%
ENVIRONMENTAL KPI - CO_2 direct	107% of case 3.1
ENVIRONMENTAL KPI - CO_2 indirect	107% of case 3.1
SOCIAL KPI - Injury rates vs work patterns	0.97 / year / 100 employees
SOCIAL KPI - Lost days / absenteeism	1.84 / year / 100 employees
TBL SUSTAINABILITY INDEX	0.843

Table 3 - KPI and TBL sustainability index results for the full rate case

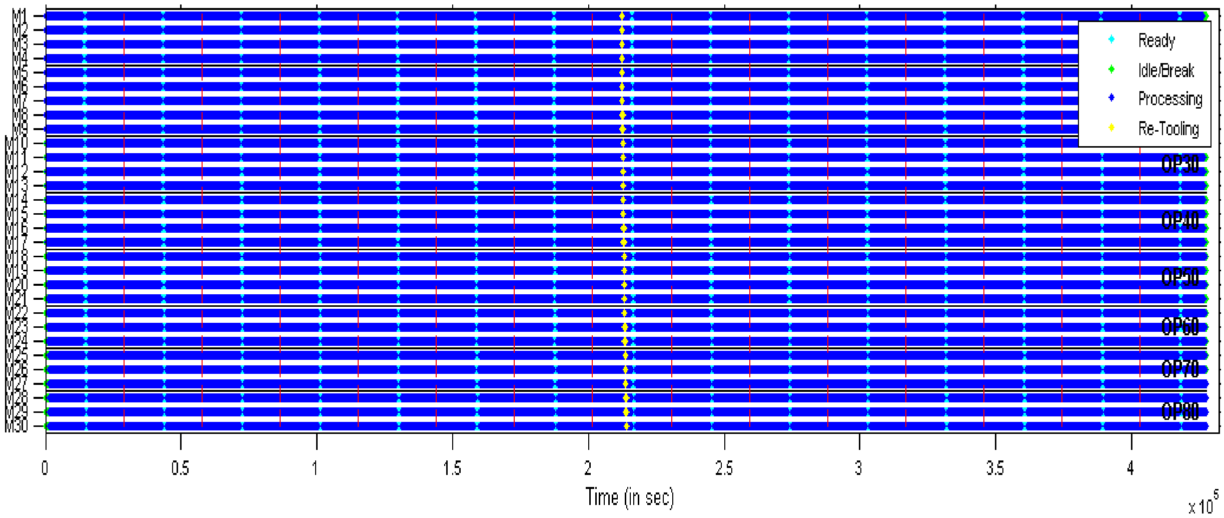

Figure 4 – Full week production pattern for the full rate case

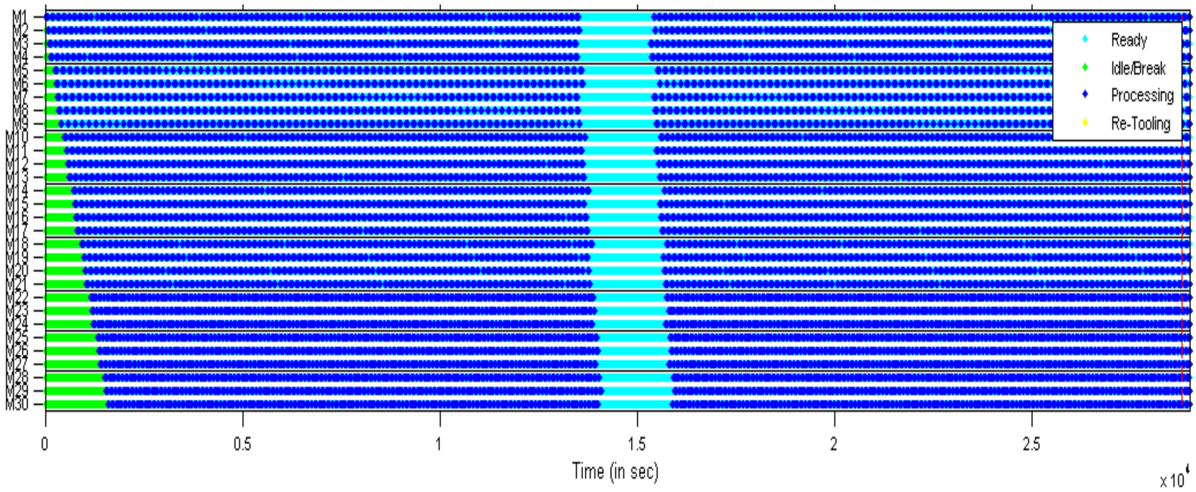

Figure 5 – Full shift production pattern for the full rate case

3.3. Optimal TBL Sustainability

Based on the Default Case (A numbers of units) but with the Capability to switch the machines to Stand-By and to vary the Work Shift Patterns.

ECONOMIC KPI - Availability	93.7%
ECONOMIC KPI - Performance Efficiency	32%
ENVIRONMENTAL KPI - Energy consumption	61% of case 3.1
ENVIRONMENTAL KPI - Energy efficiency	1.08
ENVIRONMENTAL KPI - Saved energy	39%
ENVIRONMENTAL KPI - CO_2 direct	92% of case 3.1
ENVIRONMENTAL KPI - CO_2 indirect	92% of case 3.1
SOCIAL KPI - Injury rates vs work patterns	0.49 / year / 100 employees
SOCIAL KPI - Lost days / absenteeism	0.44 / year / 100 employees
TBL SUSTAINABILITY INDEX	0.587

Table 4 - KPI and TBL sustainability index results for the optimal TBL sustainability case

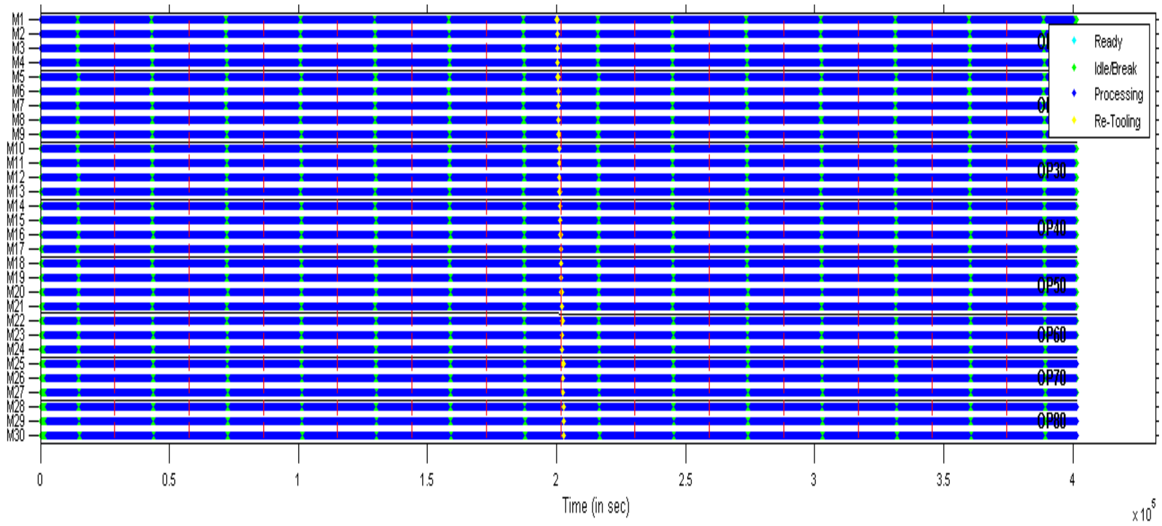

Figure 6 – Full week production pattern for the optimal TBL sustainability case

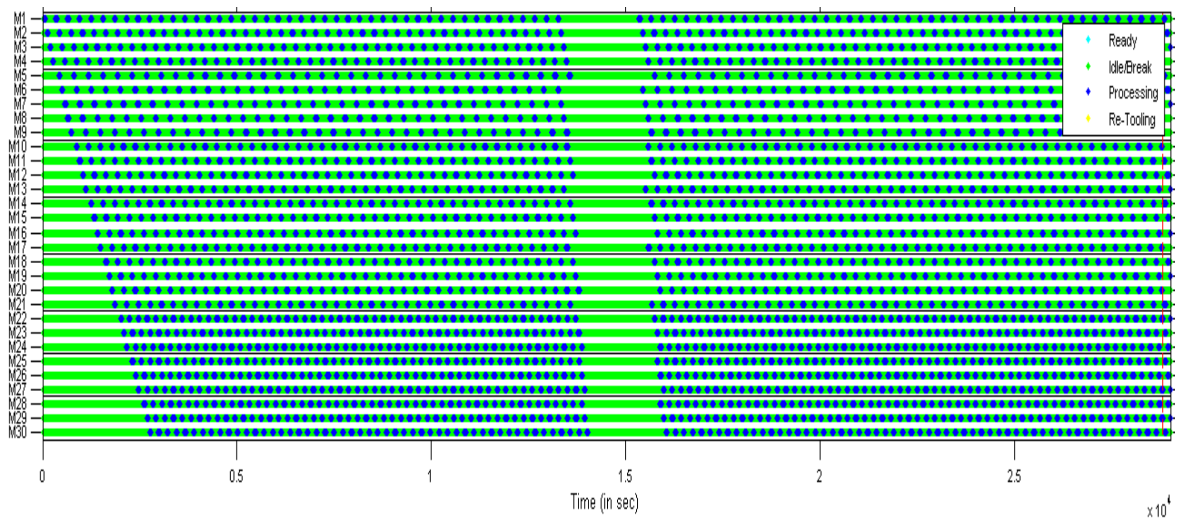

Figure 7 – Full shift production pattern for the optimal TBL sustainability case

3.4. Variable Production (TBL including machine shutdowns)

Two scenarios for reduced & increased production respectively.

3.4.1. Reduced production (70% of A units) with the capability vary the production speed and set the machines to standby between machinings.

ECONOMIC KPI - Availability	93.3%
ECONOMIC KPI - Performance Efficiency	24%
ENVIRONMENTAL KPI - Energy consumption	60% of case 3.1
ENVIRONMENTAL KPI - Energy efficiency	1.1
ENVIRONMENTAL KPI - Saved energy	40%
ENVIRONMENTAL KPI - CO_2 direct	90% of case 3.1
ENVIRONMENTAL KPI - CO_2 indirect	90% of case 3.1
SOCIAL KPI - Injury rates vs work patterns	0.31 / year / 100 employees
SOCIAL KPI - Lost days / absenteeism	0.19 / year/ 100 employees
TBL SUSTAINABILITY INDEX	0.513

Table 5 - KPI and TBL sustainability index results for the reduced production case

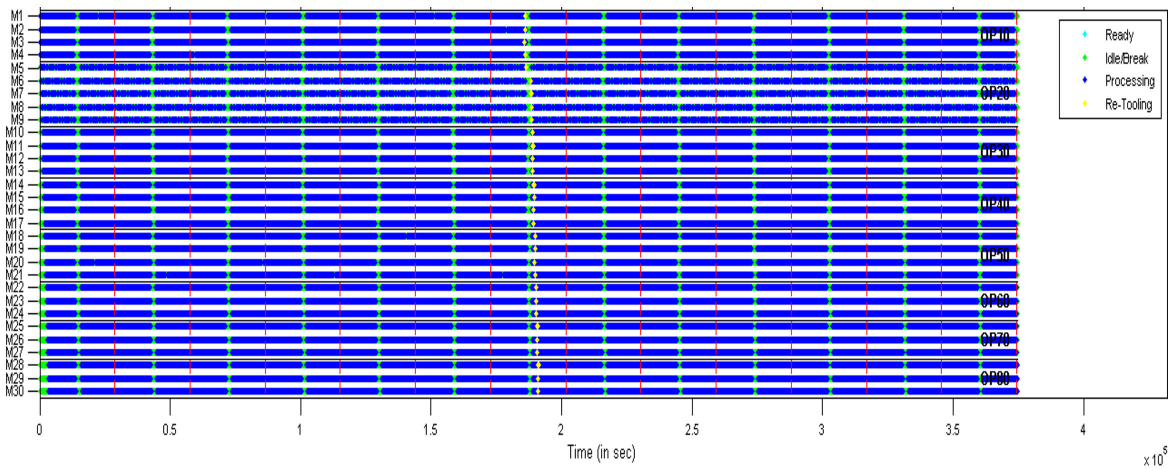

Figure 8 - Full week production pattern for the optimal reduced prouction case

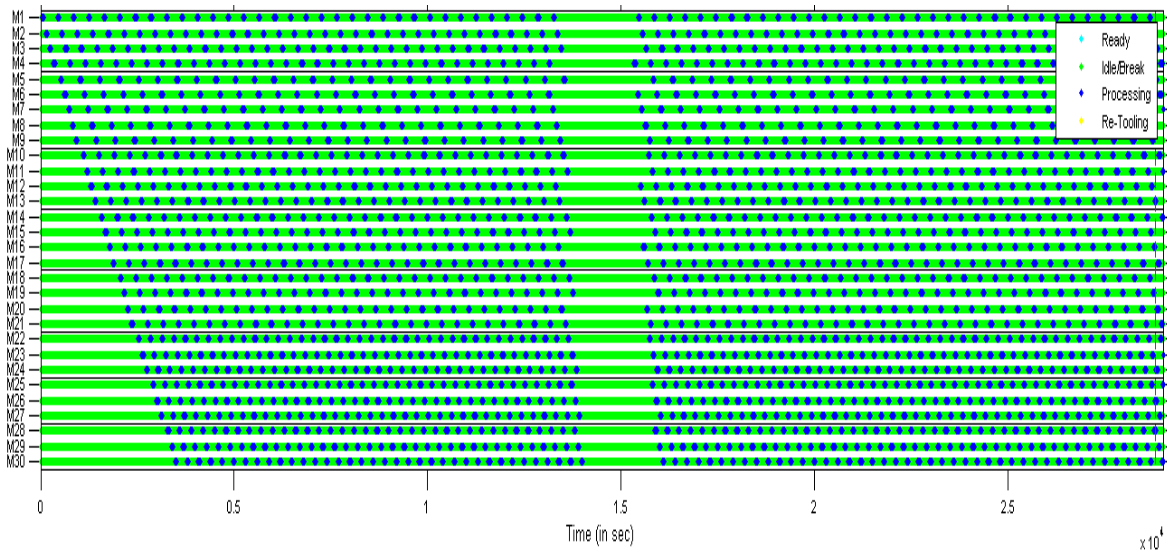

Figure 9 - Figure 7 – Full shift production pattern for the optimal reduced production case

3.4.2. Increased production Case (130% of A units) with the Capability to adjust the feed rate and the number of workers. Machines can be set to standby.

ECONOMIC KPI - Availability	93.3%
ECONOMIC KPI - Performance Efficiency	48%
ENVIRONMENTAL KPI - Energy consumption	68% of case 3.1
ENVIRONMENTAL KPI - Energy efficiency	1.07
ENVIRONMENTAL KPI - Saved energy	32%
ENVIRONMENTAL KPI - CO_2 direct	81% of case 3.1
ENVIRONMENTAL KPI - CO_2 indirect	81% of case 3.1
SOCIAL KPI - Injury rates vs work patterns	0.6 / year / 100 employees
SOCIAL KPI - Lost days / absenteeism	0.75 / year/ 100 employees
TBL SUSTAINABILITY INDEX	0.591

Table 6 - KPI and TBL sustainability index results for the increased production case

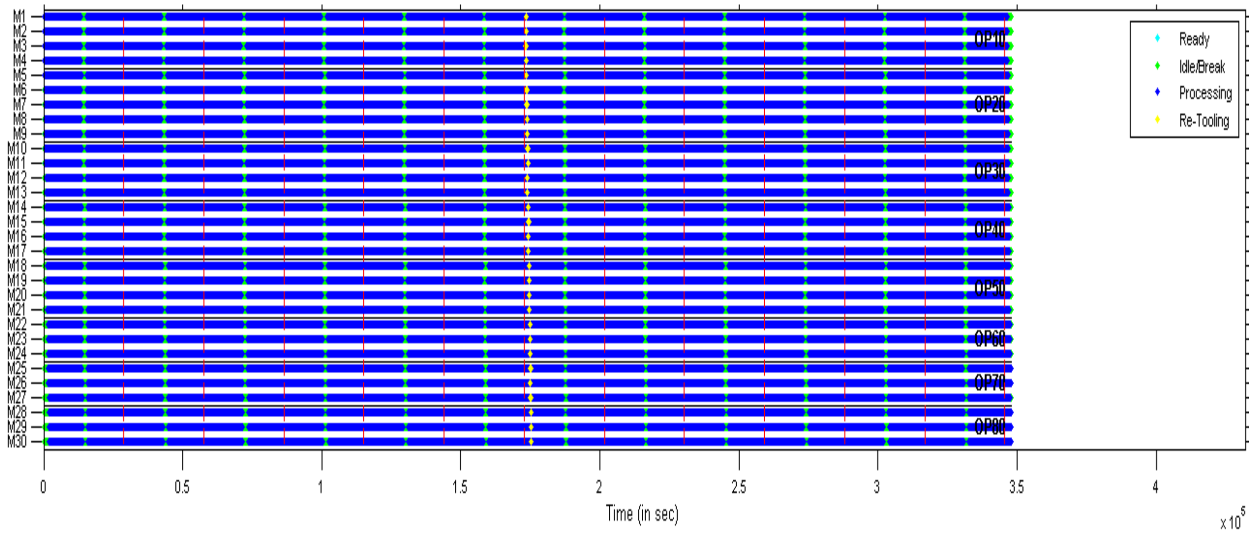

Figure 10 – Full week production pattern for the increased production case

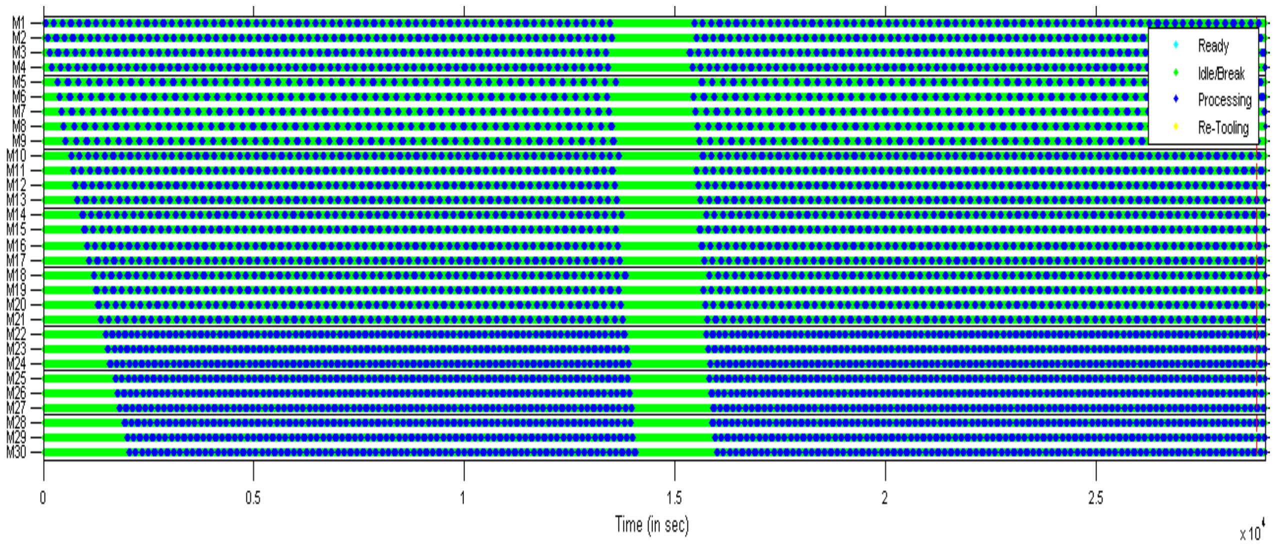

Figure 11 – Full shift production pattern for the increased production case

5 CONCLUSIONS

In this document, a specially developed Smart Sustainability Optimization (SSO) tool in the context of the FoFdation project is applied for an automotive industry case in order to illustrate how it works in advanced sustainability scheduling beyond any MES Scheduler and when investigating potential shop-floor dynamics/flexibility. The SSO is an advanced tool aiming to optimize production schedule for total (TBL) sustainability (energy, social, emissions) and to propose alternative process layouts and accompanying schedules in cases of unforeseen problems (e.g. machines breakdowns, rush orders, etc.) without disturbing the physical layout of the shop floor. It is successfully applied in the CRF shop floor providing optimal alternative plans for the selected scenarios.

From the comparative table below, it is evident that the developed algorithm produces optimal schedules for the triple-bottom-line sustainability of all cases when compared to the default case. For example in the optimal production increase case, the TBL sustainability index is better than the default case even though the social KPIs are 50-100% higher than the default case.

CASE	Default	Theoretical max	Optimal TBL	Opt. reduced	Opt. increased
Availability	93.7%	93.7%	93.7%	93.3%	93.3%
Performance Efficiency	32%	68%	32%	24%	48%
Scrap ratio					5%
Quality					95%
Energy consumption	100%	107% of case 3.1	61% of case 3.1	60% of case 3.1	68% of case 3.1
Energy efficiency	1	1	1.08	1.1	1.07
Saved energy	0%	0%	39%	40%	32%
CO_2 direct	100%	107% of case 3.1	92% of case 3.1	90% of case 3.1	81% of case 3.1
CO_2 indirect	100%	107% of case 3.1	92% of case 3.1	90% of case 3.1	81% of case 3.1
Injury rates vs work patterns	0.49 / year / 100 employees	0.97 / year / 100 employees	0.49 / year / 100 employees	0.31 / year / 100 employees	0.6 / year / 100 employees
Lost days / absenteeism	0.44 / year/ 100 employees	1.84 / year / 100 employees	0.44 / year / 100 employees	0.19 / year/ 100 employees	0.75 / year/ 100 employees
TBL SUSTAINABILITY INDEX	**0.619**	**0.843**	**0.587**	**0.513**	**0.591**

Table 7 – KPI and TBL sustainability index results comparison of all production cases

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