An Optimal Multiobjective Production System: A Case Study

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***Abstract*— In this paper, a case study is presented to improve the performance of a Tires Production System implemented as a Material Requirement Planning. In our proposal, the Master Production Schedule is calculated from a percentage of the demand's forecast per period, and production begins with the arrival of customer orders. The improvement of Tires Production Systems comprises to work with the multi-objective genetic algorithm method NSGA-II and with the results comparison of the duo Simulated Binary Crossover - Parameter based against the Whole Arithmetical Crossover Mutation - Mutation Uniform. The simulation results show that the minimum values are obtained with the pair Simulated Binary Crossover - Mutation-based Parameter, and also in fewer generations number.**

Keywords-multiobjective optimization; nsga-II; production systems; genetic algorithm

I. INTRODUCTION

This research starts with the need to improve the performance of a Tire Production System (TPS). TPS is implemented as a Material Requirements Planning (MRP) System. The improvement is made at the Planning and Production Control System (PPCS) of the TPS in order to satisfy demand without increasing inventory.

A PPCS can be implemented as a Push System (PHS) or as a Pull System (PLS). A MRP is a type of Push System [1], while a Kanban System is considered to be a Pull System [1]. In a PHS, the Forecasted Demand represents the signal to start production, and its main feature is to satisfy the demand in exchange for an inventory of finished products. A Kanban System starts production with the arrival order signal; its main feature is to decrease inventory in exchange of the increasing the risk to do not meeting the demand.

Both PPCS approaches (PLS and PHS) were created for different manufacturing environments. PLS works well in environments of assembly of components, where components are assembled into finished products, while PHS works well in processes that supply products to other production processes as well as processes that involve perishable products [2].

Since late 80's, some researchers have explored different combinations of the advantages of PHS and PLS and they have defined a new kind of PPCS known as Hybrid Push-Pull Systems (HPPS). These kinds of systems merge the characteristics of PHS and PLS in order to improve Production Systems performance [1].

The objective of this paper is to improve the performance of a TPS. This is accomplished by taking the advantages from both PHS and PLS. It is proposed to use MRP for Master Production Schedule (MPS) and Material Plan (MP). For the execution of the production, the arrival of the orders as a signal to start production is proposed. The performance is measured with two indicators: Unmet Demand and Raw Material Inventory. A Multiobjective Genetic Algorithm (MGA) is used in order to find the minimum values of performance indicators.

The paper is organized as follows: the related literature with the HPPS that improve the performance of a MRP system is cited in Section II. Section III presents the proposal to improve the TPS on study, considering the elements to integrate to the MRP system implemented in the TPS, the MGA method and the crossover and mutation techniques; in the materials and methods section, the general methodology is defined as well as the structure of the MGA method and the information related to the case study. The results and conclusions are presented in Section V and Section VI, respectively.

II. LITERATURE REVIEW

This section considers the researches related with HPPS that improve the performance of a production system from a MRP system. Below, authors and description of the HPPS are presented:

- Hall [3] uses MRP and Kanban synchronized in the joint point of shop floor and planning, in order to start to produce.
- Vaughn [4] uses MRP for medium to long term planning and uses Kanban for shop floor.
- Lee [5] integrates MRP and Just in Time in a single framework, to take the planning advantage of MRP and the execution advantages of JIT.

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- Ke et al. [6] use a strategy composed by a Push element for the procurement and a Pull element for production.
- Takahashi et al. [7] integrate the Push and Pull controls to calculate orders for the assembly and distribution stages using PHS and PLS respectively.
- Nagendra [8] uses JIT/Kanban in the shop floor and MRP for planning process.
- Gupta et al. [9] make a selection of the number and size of Kanban implemented in an MRP system.
- O'Grady [10] presents a model in which the demand is the signal for MRP to make the planning stage, and the execution stage works with PLS.
- Bushée et al. [11] make a method for scheduling job shops that combines PHS and PLS.
- Beamon et al. [12] apply the PHS from the beginning of the process until the components are produced; in these points the system changes to PLS to assemble the components into finished products.
- Flapper et al. [13] embed JIT into MRP in three steps, from a production process operated by MRP. Step 1: create a logical line flow through rapid material handling; Step 2: use a PLS on the logical line; Step 3: make the layout in a flow line.
- Huq et al. [14] use a PLS in a job shop with some variations in: processing times, load levels, and machine breakdowns.
- Lin et al. [15], base the production system on the forecast of production to produce the components of the final products with the push system, and the final products are assembled according to customer orders, with Pull system.

HPPS were made to improve the indicators performance of a PPCS, which highlights the inventory of raw materials and demand satisfaction, among other performance indicators.

According to the literature reviewed, the proposed HPPS are structured so that the main advantages of each PHS and PLS, i.e., MRP in the planning stage and JIT at the production stage.

The proposed HPPS do not consider changes in the proportion of Forecasted Demand in the planning production stage, while working with PHS and PLS in the production stage.

III. PROPOSAL

Based on the literature review, a proposal is made to improve a TPS. The TPS under study operates according to a MRP system. The improvement is based under the following considerations: the TPS in the stages of MPS and MP will operate as a MRP system [16], In the Push stage, the arrival orders as the starting production signal is proposed, like in a Pull System [17].

To improve the performance of the TPS, it is proposed to calculate the MPS from a percentage of the forecasted demand and to produce according to demand. TPS improvement is measured through the performance indicators: Raw Materials Inventory and Unmet Demand. The Raw Material Inventory is the amount of raw material accumulated at the beginning of the production process at end of period. Unmet Demand is the amount of demand that is not satisfied at the end of the period.

To improve the TPS, a MGA is used. The MGA are used when an optimization problem has two or more objective functions and the search space is very large. The problem to improve the TPS is an optimization problem consisting in two objective functions and continuous decision variables. The search space size is calculated with a combination of the decision variables of all the periods. This problem is defined later. According to our previous statements, it can be said that it is appropriate to use a MGA.

There exists some methods of MGA in the literature. NSGA-II proposed by Deb [18] is proven to have a better performance than other similar methods, such as Pareto-archived Evolution Strategy (PAES) [19] and Strength-Pareto Evolutionary Algorithm (SPEA) [20]. These three MGA methods use elitism. NSGA-II gets better results with real code representation than binary code representations [18]. These are the reasons why this method is selected to improve the TPS.

NSGA-II proposes to work with Simulated Binary Crossover (SBX) and the Parameter-based Mutation (PBM), for validation experiments [21]. However, in this research, the mutation and crossover techniques are alternated, in one side we use SBX along with PBM, and on the other side the Whole Arithmetical Crossover (WAX) is used along with Uniform Mutation (UM) [22]. All crossover and mutation techniques used in this work, are defined in the next section.

To improve the TPS, there is an optimization problem where the objective functions are: to Minimize Raw Material Inventory and to Minimize Unmet Demand, the decision variables are the Percentages of Demand Forecasted per period and the Demand has random arrivals according to a Poisson Probability Distribution with known mean.

To get the minimum values of performance variables for the TPS, both crossover and mutation techniques are compared in order to find which of the two pairs defined previously show better values on performance indicators: Raw Materials Inventory and Unmet Demand, as well as which of the techniques takes less time. The two pairs are chosen because both are applied to real-coded representation in genetic algorithms and both use bounds for the decision variables; moreover, the crossover is applied to all elements of the chromosome, by genetic algorithms.

IV. MATERIALS AND METHOD

In this section, the following is described: 1) the methodology applied to improve the TPS, 2) the MGA used for simulation including the crossover and mutation techniques as well as the evaluation function, and 3) the case study.

A. *Methodology*

The methodology used in this research is mentioned below:

- Propose the improvement of TPS with MGA.
- Describe the Multiobjective Genetic Algorithm to improve the TPS.
- Define the case study.
- Simulate the Multiobjective Genetic Algorithm to improve TPS, considering the two pairs of crossover and mutation.
- Compare the results of the two pairs of crossover and mutation.
- Analyze the results.
- Select the pair of crossover and mutation with better results.

All elements of the methodology are described and performed in different sections of the paper.

B. *Description of the Multiobjective Genetic Algorithm to improve the TPS.*

NSGA-II method is the basis for building the MGA to improve the TPS performance, it has the following characteristics: the representation of the variables is in real code, and Inventory of Raw Materials and Unmet Demand in the system are the two objective functions to evaluate. SBX - PBM and WAX-UM are used for crossover and mutation.

1) *Crossover and Mutation techniques*

In this work, two methods of crossover and mutation are applied. They are described below.

a) *Simulated Binary Crossover (SBX)*

The formulas for Simulated Binary Crossover [21] are presented below:

- Create a random number *u* between 0 and 1.
- Find a parameter β_q, as follows:

$$\beta_q=\begin{cases}(u\propto)^{\frac{1}{nc+1}} & if\ u\ \le \frac{1}{\propto}\\ \left(\frac{1}{2-u\propto}\right)^{\frac{1}{nc+1}}, & otherwise\end{cases}$$

where $\propto = 2 - \beta^{-(nc+q)}$ and β is calculated as follows:

$$\beta = 1 + \frac{2}{y2 - y1}\min[(y_1 - y_l), (y_u - y_2)]$$

The parameter y is assumed to vary in the interval $[y_l, y_u]$.

The children solutions are then calculated as follows:

$$c_1 = 0.5\ [\ (y_1 + y_2) - \beta q\ |y_2 - y_1|\ ]$$
$$c_2 = 0.5\ [\ (y_1 + y_2) + \beta q\ |y_2 - y_1|\ ]$$

It is assumed that $y_1 < y_2$.

b) *Parameter Based Mutation (PBM)*

The methodology to calculate the Parameter Based Mutation [21] is presented below:

- Create a random number *u* between 0 and 1.
- Calculate the parameter δ_q as follows:

$$\delta_q=\begin{cases}[2u+(1-2u)(1-\delta)^{nm+1}]^{\frac{1}{nm+1}}-1,\\ if\ u\ \le 0.5\\ 1-\ [\ 2(1-u)+2(u-0.5)(1-\delta)^{nm+1}]^{\frac{1}{nm+1}},\\ otherwise\end{cases}$$

δ=min {[(y- y_l),((y_u-y)]/(y_u- y_l)}.

- Calculate the mutated child as follows:

$$c = y + \ \delta q\ (\ y_u - \ y_l\ )$$

c) *Whole Arithmetical Crossover (WAX)*

The formulas for Whole Arithmetical Crossover [22] are presented below:

$$a\ \epsilon \begin{cases}[\max(\propto,\beta),\min(\gamma,\delta)] & si\ v_k\ >\ w_k\\ [0,0]\ si\ v_k =\ w_k\\ [\max(\gamma,\delta),\min(\propto,\beta)] & si\ v_k < \ w_k\end{cases}$$

In order to calculate *a*:

$$\propto= \frac{l_k^w - w_k}{v_k - w_k} \quad \beta= \frac{u_k^v - v_k}{w_k - v_k} \quad \gamma = \frac{l_k^v - vw_k}{w_k - v_k} \quad \delta = \frac{u_k^W - w_k}{v_k - w_k}$$

Where each value v_k exist within range $[l_k^v, u_k^v]$ and each value w_k exist within range $[l_k^w, u_k^w]$.

The children are constructed as follow:

$P_1 = (v_1, \dots, v_m)$ and $P_2 = (w_1, \dots, w_m)$

$$c_1 = [\ w_1 * a + v_1 * (1-a), \quad \dots, \quad w_m * a + v_m * (1-a)]$$
$$c_2 = [\ v_1 * a + w_1 * (1-a), \quad \dots \quad , \quad v_m * a + w_m * (1-a)]$$

d) *Uniform Mutation*

The methodology to calculate Uniform Mutation [22] is described below:

Given $P = [\ V_1, V_k', V_m\ ]$, the mutated individual will be $P' = [\ V_1, V_k', V_m\ ]$. $V_k' = rnd(low\ bound, upper\ bound)$.

The minimum and maximum ranges of the variables are used.

2) *Procedure for evaluation function*

The procedure to calculate evaluation function or fitness is described as follows. These steps are added to the NSGA-II method, and they are related to the case study:

- To input the Demand Forecasted and the number of planning periods.
- To calculate MPS. This is the multiplication of the Percentage of Forecast by Demand Forecasted, per period. The percentage of forecast takes values between 0 and 1.5.
- To generate Demand. The demand is generated randomly, following a Poisson distribution with known mean.
- To calculate the evaluation functions or Fitness: Raw Material Inventory and Unmet Demand.

if MPS (i , j) = Demand (i , j)
    Raw Material Inventory (i , j) = 0
    Unmet Demand (i , j) = 0

if MPS (i , j) < Demand (i , j)
    Unmet Demand (i , j) = (Demand (i , j) – MPS (i , j) / Demand (i , j)
    Raw Material Inventory (i , j) = 0
if MPS (i , j) > Demand (i , j)
    Raw Material Inventory (i , j) = (MPS (i , j) – Demand (i , j) / MPS (i , j)
    Unmet Demand (i , j) = 0;

Fitness (i) = [∑ Unmet Demand (i , j)
    ∑ Inventory (i , j)]

- To obtain the final solution: get the set of nondominated solutions of the final population P, and then select the minimum value, one that provides the mimimum accumulated values of Raw Materials Inventory and Unmet Demand.

Calculations of Raw Material Inventory and Unmet Demand are performed for each set of solutions generated by the algorithm; *i* represents the set of solutions of each population, and *j* represents the number of planning periods.

To construct the MGA that improves the TPS the steps of the NSGA-II method are applied. The way of making the crossover and mutation must be changed with SBX-PBM and WAX-UM, with the respective change on the steps above described for the evaluation function.

The values of the parameters for the MGA are: population size of 100, probability of crossover 90%, mutation probability of 17%, maximum number of generations of 250. The probability of Mutation is (1 / (number of decision variables)). The value of *nc* for SBX calculation is 20 and *nm* and for PBM calculations is 20 as well. These values are set as recommended by NSGA-II method. Chromosome is formed as follows: [Percentage of forecast to period 1 … Percentage of forecast of period *p*], the number of genes depends on the number of periods.

C. Case Study

The TPS produces 30 different tire sizes; it has a total production capacity of 400,000 tires monthly, TPS makes its planning for the next 6 months, the average demand is 390,000 tires per month. The forecast of the demand for the 6 periods is in Table I.

TABLE I. DEMAND FORECASTED BY PERIOD

Forecast of Demand					
Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
389.509	390.558	390.210	390.905	389.351	388.695

Simulations are performed to find the minimum values of Inventory of Raw Material and Unmet Demand for TPS. The results are analyzed by SBX-PBM and WAX-UM; the duo that generates the minimum values for both objective functions and do it in less generations, is defined as the final solution for the case study. The simulations are performed in MATLAB 2012-A ®.

D. Simulation Procedure

The simulation procedure for MGA to improve TPS starts with the input data of the case study and the parameters of NSGA-II method, considering the evaluation function shown in B 1. The simulation is carried out using MGA with crossover and mutation SBX-PBM and with WAX-UM techniques.

V. RESULTS

The results of the simulation with SBX-PBM and WAX-UM are presented in Table II and Table III, respectively. These are the percentages of the forecast. Figures 1 to 5 show the values of Raw Material Inventory and Unmet Demand, with SBX-PBM and WAX-UM, for the five simulations with 250 generations.

The graphics in the left side in all figures show the results obtained by the SBX-PBM; they achieve the minimum values for Raw Materials Inventory and Unmet Demand, between 50 and 100 generations. Also, the graph shows that from generation 100 the values achieved were very similar, and very close to zero. They also notice that the values generated for the two objectives initially, reach a value of 50. Both objectives are minimized at the same time for SBX-PBM.

The graphics on the right side in all figures show that the values of the objectives reach values up to 75 at the beginning, for WAX-UM. The behavior of the values Inventory of Raw Material and Unmet Demand fail to stabilize at 250 generations and values generated do not reach the minimum in both objectives at once.

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TABLE II. RESULTS OF SBX-PBM BY SIMULATION AND BY PERIOD

Simulation	Period					
	1	2	3	4	5	6
1	1.0018	0.9986	0.9978	0.9974	1.0003	1.0036
2	1.0030	0.9997	0.9983	0.9977	1.0021	1.0034
3	1.0003	1.0009	0.9970	0.9981	1.0025	1.0031
4	1.0007	0.9962	0.9985	0.9957	1.0017	1.0035
5	1.0013	0.9986	0.9994	1.0007	1.0015	1.0020

TABLE III. RESULTS OF WAX-UM BY SIMULATION AND BY PERIOD

Simulation	Period					
	1	2	3	4	5	6
1	0.9982	0.9936	1.0187	0.9897	1.0098	1.0074
2	0.9735	0.9929	0.9853	0.9901	0.9909	1.0079
3	0.9909	1.0314	1.0109	0.9938	0.9994	0.9778
4	0.9981	0.9887	0.9997	1.0029	1.0076	1.0415
5	1.0041	0.9772	0.9844	0.9929	0.9994	0.9996

VI. CONCLUSIONS AND FUTURE WORK

After carrying out the simulation of the MGA to optimize the TPS improved by making changes in crossover and mutation techniques using the pairs SBX-PBM and WAX-UM, and based on the results depicted in the graphics of the section above, it can be concluded that:

- SBX-PBM gets better results for the two objectives: Raw Materials Inventory and Unmet Demand than WAX-UM.
- SBX-PBM reaches minimum values in fewer generations than WAX-UM, for both objectives.
- SBX-PBM gest values closer to zero than WAX-UM.

The best performance in relation to Inventory of Raw Material and Unmet Demand is generated for the pair SBX-PBM. Therefore it can be concluded for this case study that TPS is improved with MGA using the techniques of crossover and mutation SBX and PBM.

It is recommended to apply the improvements proposed for TPS, with demand arrivals and production capabilities proven in the case study, as well as demand arrivals following a Poisson distribution and the parameters fixed for the NSGA-II.

According to the objective, MGA should be used to improve TPS, with the technique of crossover and the technique of SBX mutation with PBM, with the following parameters *nc* = 20 and *nm*= 20, with 90% probability of crossover, 17% probability of mutation, 250 generations, population size of 100, for 6 planning periods.

As future work, it is planned to set this work as a Hybrid Push-Pull System. It is planned also to experiment with different production capabilities.

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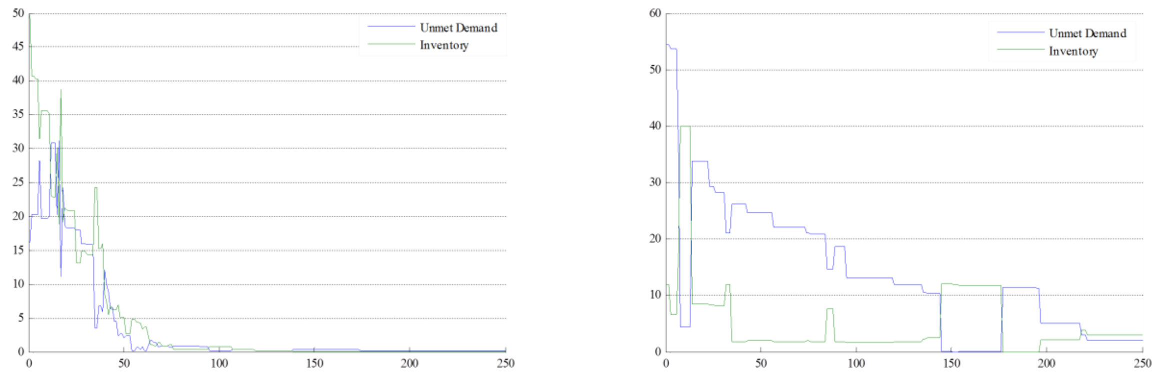
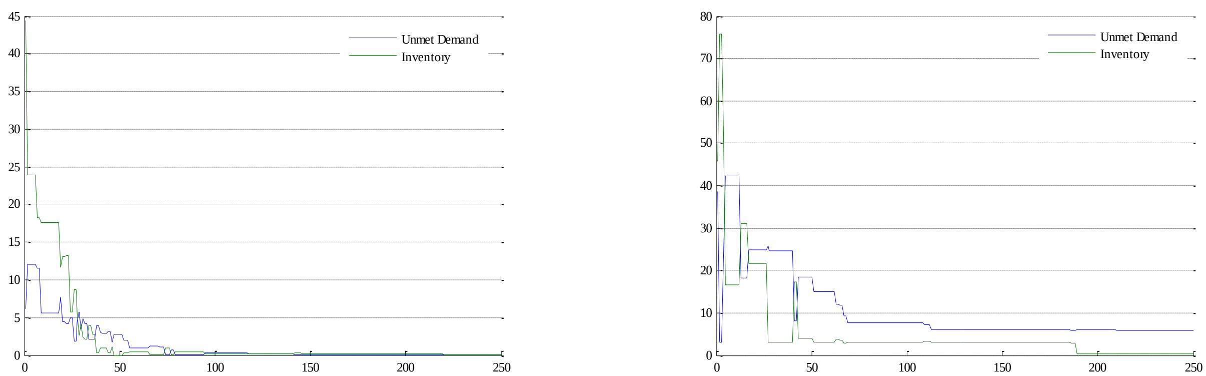


SBX-PBM WAX-UM

Figure 1. Simulation 1



SBX-PBM WAX-UM

Figure 2. Simulation 2

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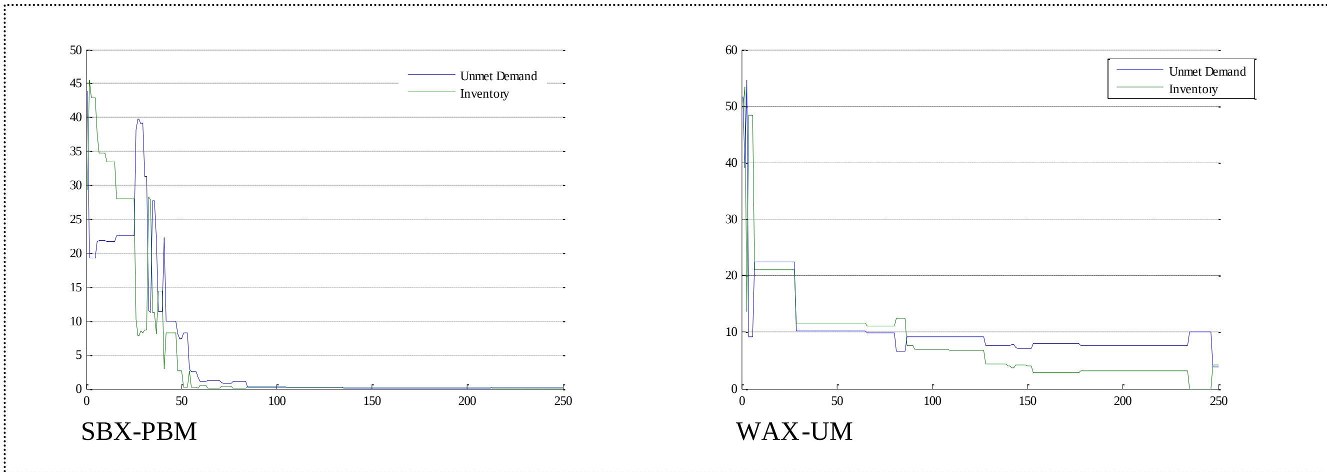

Figure 3. Simulation 3

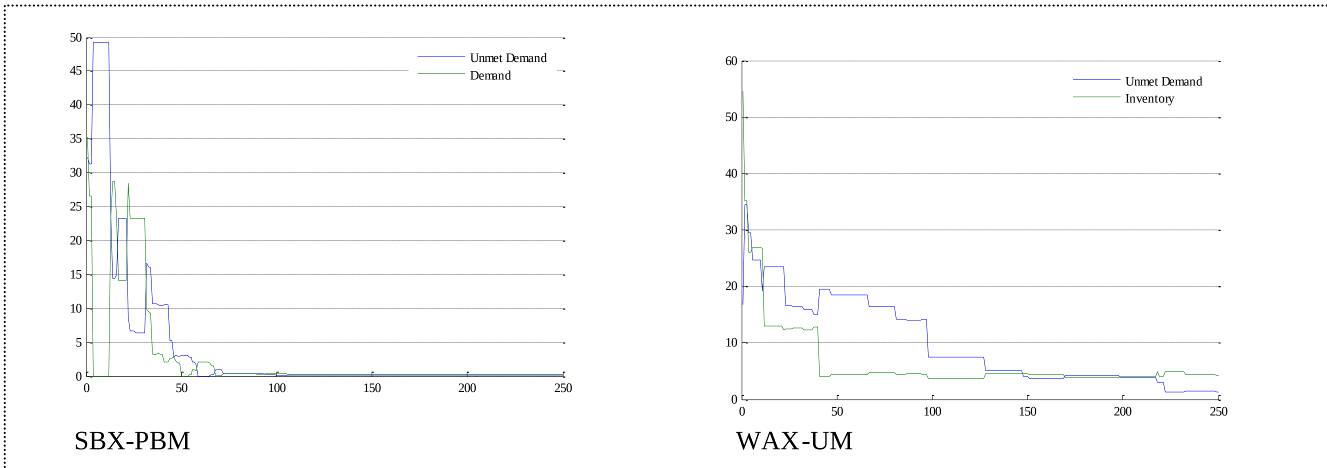

Figure 4. Simulation 4

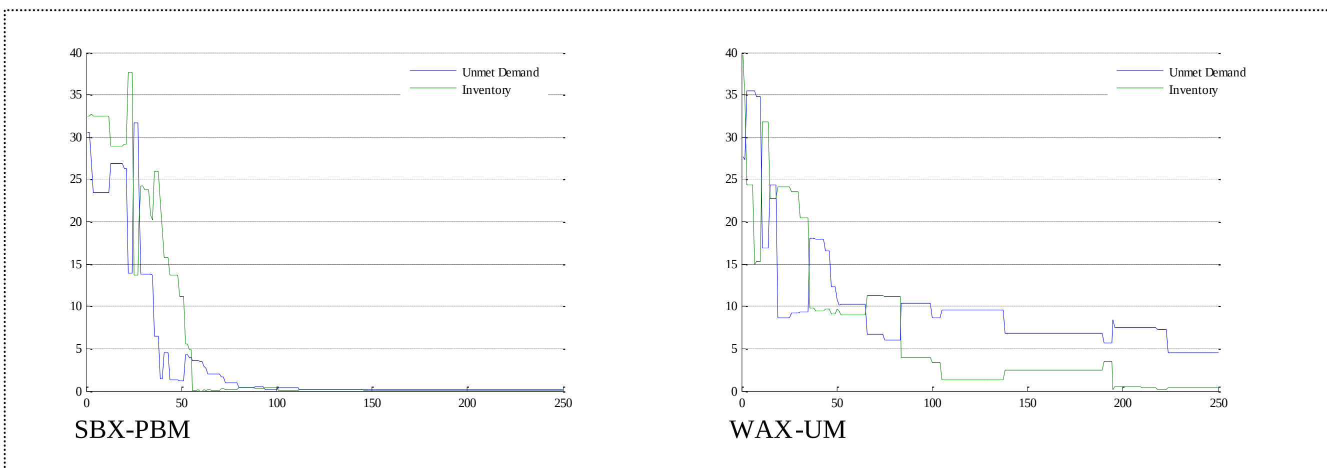

Figure 5. Simulation 5