Flexible Planning Model for a High Tech Company with High Volume–High Mixture

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***Abstract*—Within an electrical test planning system in the semiconductor industry, various models that allow a better utilization of installed capacity were developed. The workflow in the plant and the information flow in the electrical test planning area were analyzed in order to minimize setup times on the equipment. A paradigm shift is proposed, with which planning is done at the product family level instead of at the level of the part number, always starting with priority products required by the market.**

***Index Terms*— production planning, setup time, product family, semiconductors, electrical test**

I. Introduction

The planning process is a common problem for any company, unresolved systematically because of the large number of variables which affect the decisions to be taken. That makes it difficult to optimize the makespan. In a high tech semiconductor-edge company, the production planning is affected in productivity because of the high quantity of machine changeovers (setups). The manufacturing work plan core is given by the sequence of the production orders. When an order is delivered to the production supervisor to execute, it is imperative that the output of a schedule reduces the idle times caused by equipment setups. Beforehand, it is known that it is not the same having a small changeover (a recipe or a tool), or a big one, when the product dimension is changed, thus a greater productive capacity is lost. Currently, the machine loading in this semiconductor company is realized at the product level with lack of visibility on the products that are similar by their geometry. For this reason, the production planner usually is not aware of the transition time from one product to another; this practice leads to a machine downtime for a product change, and it reduces productivity.

In the company, the machine downtime caused by a changeover occurring in the production is out of control, and the detected root cause is the method of the machine allocation order; i.e., the first machine available is assigned to the next lot. Moreover, it does not take into account that the lot change time is different for different sequences of products. Therefore, it is proposed to limit the changeover options for those handled within the same product geometry to form production batches, which do not require major setups in-between. This categorically reduces the idle time due to the activities of the change or adjustment of a tool.

The objective of this work is to develop a flexible model for the manufacture planning in the electrical test area of a semiconductor high-tech company, with the characteristics of high-mix and high-volume to allow: a) Cycle makespan reduction, b) Delivery on time, and as a consequence, c) Manufacture cost minimization. To achieve this goal, the workflow in the company and the information flow in the electrical test area have been studied, the setup structure was analyzed, and the manufactured products were grouped into families on the basis of similarity in geometries. The grouping was performed using the main idea of the Group Technology: the products must be sorted out into groups according to their design or manufacturing attributes, such as shape, size, surface texture, material type, raw material estate [1][2]. Using the technical similarities of the products within a group to schedule lots in batches permits to reduce essentially the setup time on the machines.

The makespan minimization problem that considers setup times and batch processing on the machines is frequent in the scheduling literature due to its importance in industries, and the variability of statements. It is NP-hard even for the easiest shop models. Given the problem complexity, the solutions have a high computational cost. So, Damodaran and Srihari [3] proposed a mixed integer formulation to minimize the makespan in a flowshop with batch processing machines. Manjeshwar, Damodaran and Srihari [4] presented a simulated annealing algorithm to minimize the makespan in a flowshop with two batch-processing machines. Luo, Huang, Zhang, Dai and Chen [5] used a genetic algorithm for two-stage hybrid batching flowshop scheduling with blocking and machine availability constraints. Yazdani and Jolai [6] considered optimal methods for the batch processing problem with makespan and maximum lateness objectives. A review of models and algorithms, which considers batch processing of lots with similar characteristics, was presented in [7]. In [8], a review and analysis of some works about scheduling of batch processing in the semiconductor industry was performed. Details of the scheduling methods with setups for a hybrid flow shop with batch processing can be found in [9][10]. In this work, we propose an alternative to high-cost algorithms, which are frequently unacceptable in real conditions of the semiconductor manufacturing.

This document is structured as follows: Section 2 presents some ideas about grouping of the products into families. In Section 3, a model of lot sequencing is exposed. Section 4

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describes the model test: test scenarios, run model and the results obtained. Finally, in Section 5 some conclusions and future work are discussed.

II. Grouping the Products into Families

A family represents all those products that share the same geometry (the size & the height) of the microcircuit and therefore, they do not require major adjustments between lots. To extract all geometries of the products declared in the business process and to group products into the families, the company product catalog and the product portfolio were considered. Table I shows the number of geometric variations in the portfolio, where approximately 67% of the geometries are active, which means that these ones form the main part in the product categorization according to the demands.

TABLE I
PRODUCT PORTFOLIO CHARACTERISTICS

Products	Quantity	Geometries	Heights
Active	556	70	11
Inactive	533	34	5
Totals	1089	104	16

By managing planning with a focus on a product family rather than on a part number (product) level, one wants to improve the planner flexibility by the information about the compatibility of the products belonging to the same family. This is more than enough to ensure the production plan execution and fulfillment when a product in the scheduled lot sequence is replaced by another one, which is available for processing.

The three product types are established when they are classified according to A-B-C categories of inventories, where category A is the highest priority, and C is the lowest one (Table II), as a function of the volumes required by every geometry, the same geometries, which are referred to in the classification of inventories established by APICS[*] [11]. The table shows that different types of the geometry are confronted with the volumes required and the product mix within the period, resulting in 66% of the demands concentrated in 35 part numbers (high volume and high frequency for the priority type A).

TABLE II
VOLUME-PRIORITY RELATION CONSIDERING TYPE AND GEOMETRY OF THE PRODUCTS

Priority	A	B	C
Characteristics	High volume, High Frequency	Middle volume, Middle frequency	Low volume, Low frequency
Quantity	65.90%	24.75%	9.35%
Part Numbers	35	114	407
Geometries	8	12	50

Based on these data, the following policies are proposed for the planning according to the following priorities that consider grouping the products into the families:

a) Load the equipment capacity assigned to a family with products of type A priority first (confirmed orders by the customers).
b) Once a product of the priority type A completed its allocation, assign a product of the priority type B of the same family (to buffer demand peaks).
c) Once products of the priority type B complete their allocation, pass to assign capacity with a family of the priority type C (to forecast the future demands).

III. Batch Sequence Modelling

To model a batch sequence, many activities were performed, starting with the definition of the setup types to set the relation product geometry - setup time. It was fixed, which adjustment is required when a lot change occurs. Following, a study of the workshop information flows was realized. This analysis allowed us to build a general model of the lot sequencing.

A. Setup types specification

The setup types were sorted according to their length from low to high as follows:

1) A *lot setup* was performed when the next lot in the sequence corresponds to the same part number or product. This adjustment process consists of the next activities: the purge of the equipment, the blower cleaning, and feeding a new lot.
2) A *recipe setup* is performed when the next lot in the sequence has a different part number and the symmetry contactor is the same as the previous lot. This minor setup holds the next activities: recipe loading, variables correlating and activities related to a lot setup.
3) A *tool setup* is performed when the next lot has a different part number and the contactors symmetry is not compatible with the current test tool. This changeover consists of: tool installation, fine tuning, recipe setup and lot change related activities.
4) A *family setup* is performed when the next batch has a different geometry, so that both machine adjustments are required (Handler & Tester). This major setup consists of: handler kit installation, handler fine tuning, tool setup related activities, recipe setup related activities, and batch setup related activities.

With this, the machine setup activities were classified by sorting the changes from a minor setup, which is the lot change, to the major one, which is the family (batch) change. The setup times follow the ranges of geometries according to Table III.

TABLE III
STANDARD CHANGEOVER TIMES FOR THE TYPE OF MACHINE – GEOMETRY RANGES

Geometric ranges	Changeover type	M1 (minutes)	M2 (minutes)
M1	Lot setup	10 +/- 2.5	8 +/- 2
1 a 3.9	Recipe setup	30 +/- 5.5	45 +/- 12.3
	Tool setup	90 +/- 13.2	135 +/- 51.4
M2	Family setup		
1.6 a 2.8		290 +/- 62.3	430 +/- 93.2
M1	Lot setup	10 +/- 2.5	8 +/- 2
4 a 6.9	Recipe setup	30 +/- 4.8	45 +/- 7.9
	Tool setup	90 +/- 7.8	98.2 +/- 35.4
M2	Family setup		
2.9 a 4.5		210 +/- 42.1	340 +/- 38.4
M1	Lot setup	10 +/- 2.5	8 +/- 2
7 a 11	Recipe setup	30 +/- 3.2	45 +/- 5.4
	Tool setup	90 +/- 6.2	89 +/- 22.1
M2	Family setup		
4.6 a 5.5		170 +/- 33.5	260 +/- 25.1

[*] American Production and Inventory Control Society.

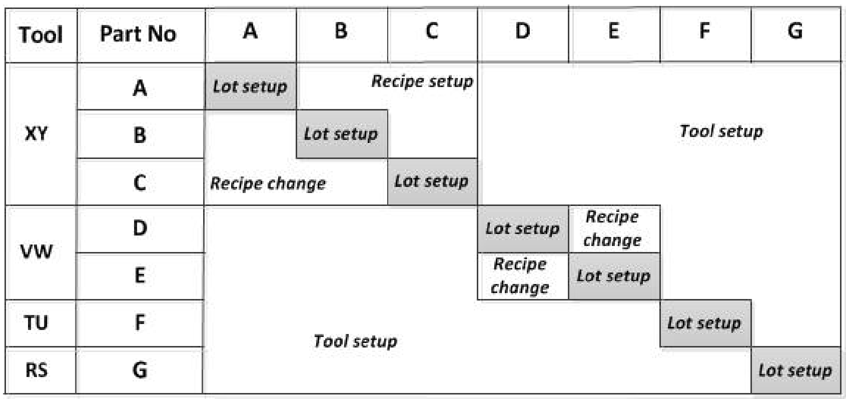

Fig. 1. Matrix morphology changes within the family.

B. Matrix of the family association

A matrix of the machine changeovers according to the setup types was prepared for the products which belong to the same family (Fig. 1). It is assumed that a minor setup corresponds to a lot change. If the next product in the sequence shares the same installed tool, then a recipe change is performed. If the next product in the sequence is not compatible with the installed tools, then a tool setup is done. Only in the case when the next product geometry is different, a family setup is needed. The individual family matrices are consolidated into a single matrix that includes all the families that are extracted from the product catalog as stated in Fig 1.

Since each family has different adjustment times, three standard ranges of the geometry combining with the type of the assigned test machine were created, this is mentioned in Table III. A single matrix was structured; it contains all the families that exist in the catalog, according to the explained ones above in Fig. 2. It is assumed that to move from one family to another one, the family changeover times must be taken to make corresponding activities: setting the handler, adjustment of tool, recipe, lot, and cleaning. If the change is related to products belonging to the same family, these times are minimal. Currently, there are 83 product families included into the matrix.

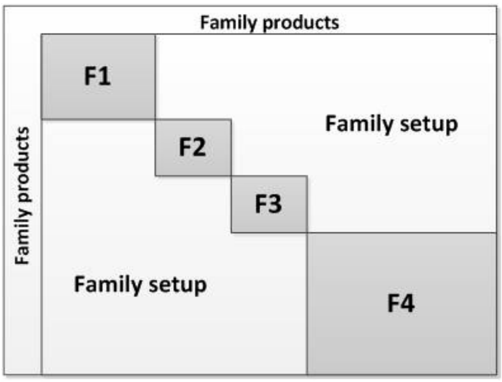

Fig. 2. Morphology of the matrix of the tool changes between four families.

C. Matrix of Tool Change Times

Due to the nature of the test process of the electronic components, there are two machine types (M1 and M2). The information is grouped first by the machine and then by the package geometry range (family). Table III shows the machine setup times for setup adjustments. When the last lot of the last batch (family) is allocated, a detailed production plan is obtained for a period of one week starting on Saturday at 12:00 a.m. and ending on Friday at 11:59 p.m. This means that each machine has totally 168 hours per week, with a tolerance of 10% of the time, representing 151.2 hrs. per week and machine. This time should contain the production processing time plus the idle time due to a changeover (lot, recipe, tool and family).

By mapping the activities of a setup on the machines, the cycle time for the activities corresponding to each setup type was validated. In addition, the setup types were documented in this study by the taxonomy data, which were taken directly from the plant and by the standards presented in Table III, which serves to quantify the transition time between lots and batches.

D. Workflow model of the production planning

The process of production planning follows the workflow denoted in Fig. 3, the same as described below:

Supply chain (SCM) - prepares the Master Production Schedule (MPS).

Industrial engineering - receives, validates and provides feedback to the Master Production Plan to indicate production capacity constraints along the production line. The Industrial Engineering Department is responsible to indicate if it is feasible to process the required volume.

Materials - receives, validates and provides feedback for material constraints to avoid delays.

Production Control - develops a detailed production plan for the current week (n) and for the next week (n+1); reviews the production plan proposed with SCM to agree with the final version of the volume planned to deliver; prepares a detailed daily production plan for the plant with the next goals to: a) Fill the installed capacity, b) Achieve cost absorption levels and c) Fulfill on time the delivery orders (OTD); release the orders to the workshop floor.

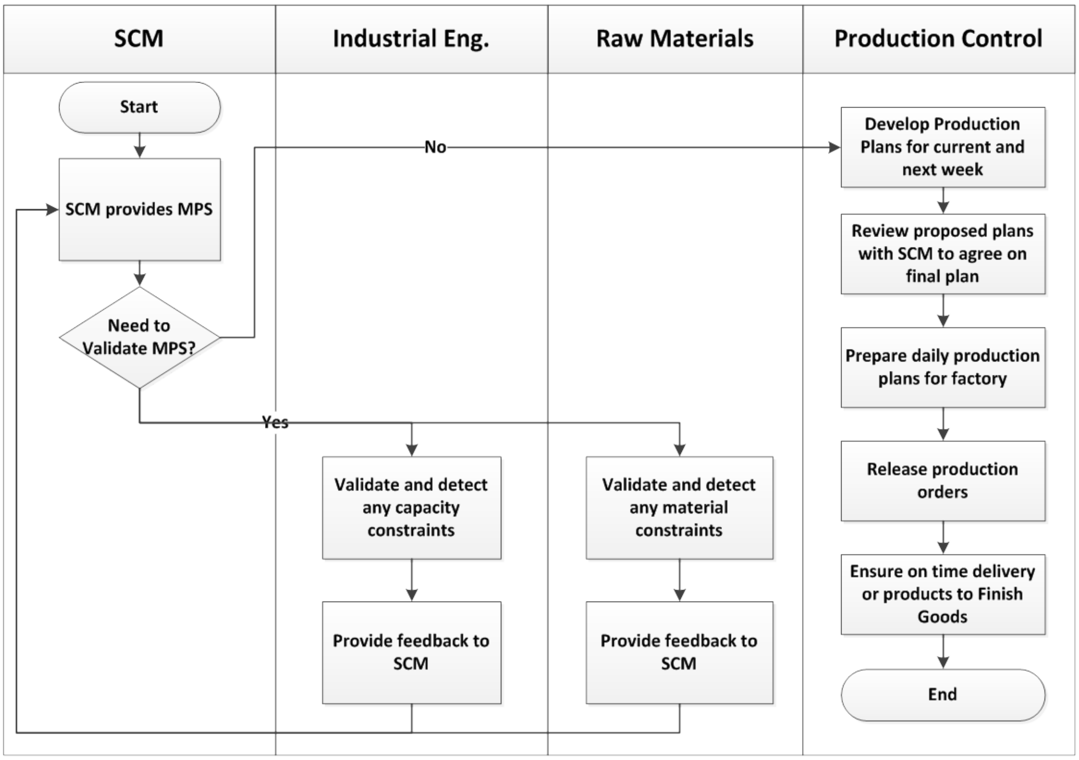

Fig. 3. General workflow of the production plan

E. General sequencing model

From a study of the information flows in the test area and an analysis of the setup structure, a general planning model was obtained, as it is shown in Fig. 4. The demand signal embedded in the MPS and the capacity analysis were used as input. The information on demand, knowledge on product characteristics allowed to obtain a classification of the products on the family level and to apply the delivery priority at the moment of assigning the lots to a machine. This is used to define the amount of the equipment that must be assigned for each family. In this general model, lots are first sequenced according to their highest priority (to produce for demand), followed by those with medium priority (to produce for inventory) and ending with the lowest priority (to produce for the forecast).

IV. PILOT TEST IMPLEMENTATION

Robustness of a model must be tested, first under simulation conditions, using for this purpose real information from the company databases, and then, testing the model under controlled conditions or in a pilot test [12]. Both of them were fulfilled in this work. The data from a sample production month were used first to perform a simulation and then comparing the process data by different stated scenarios. Once this activity was performed, a planning algorithm was implemented for selected a representative family to confirm the efficiency of the lot sequencing model. Next, the realized steps to develop the pilot test are described in detail.

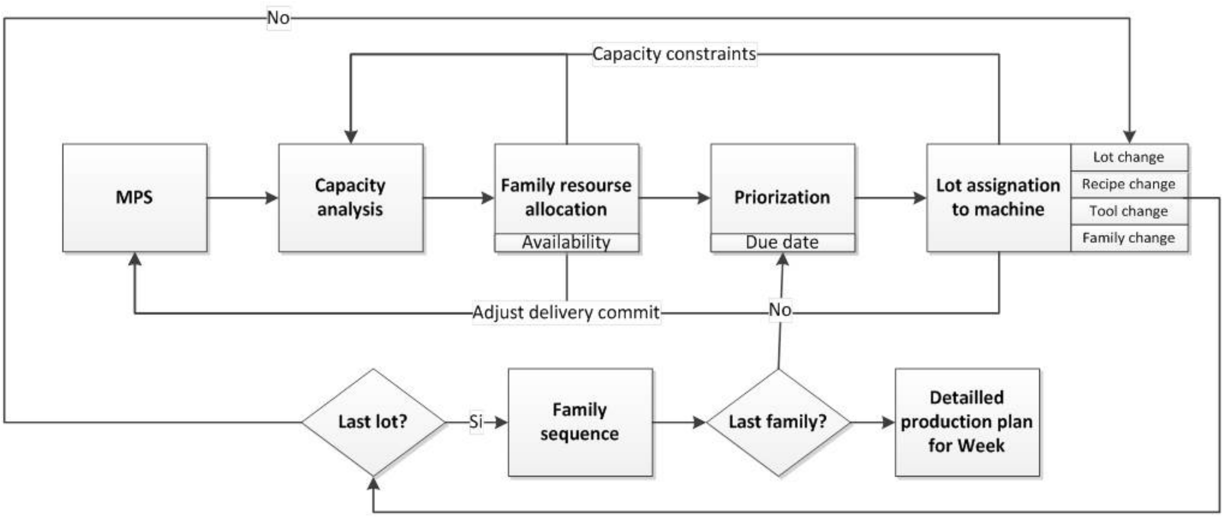

Fig. 4. General lot sequencing model.

A. *Family selection*

To simulate the model, a family type A, corresponding to the geometry 8.15x5.6, which is used in three part numbers, and a single tool type were selected (Table IV). This family represents a product volume that fills capacity equivalent to 80 M1 machines of 410 machines dedicated to perform the electrical testing of the microcircuits in the whole area.

TABLE IV
SETUP TIME MATRIX FOR FAMILY 8.15X5.6 WITH A SINGLE TOOL

Part No	Adjustments (minutes)		
	812-16	812-19	080-14
812-16	10	30	30
812-19	30	10	30
080-14	30	30	10

B. *Processed lots analysis*

In order to verify the general sequencing model (Fig. 4), the information on the production volumes and the level of demand for each manufactured part number were obtained and the processed lots were filtered to correspond only to the geometry 8.15x5.6, in a one-month test period. Table V shows an extracted section of lots with corresponding Parts No (product), which were processed during this month. There are given the volume of the processed lot and the lot cycle time. Tracking Qty is the number of pieces in the lot when it arrives to the machine; Starting Process Time denotes the lot loading time to the machine, End Process Time denotes the lot unloading machine time. Equip Number describes the machine number used to process the lot, and Trackout Qty. is the number of good devices in the lot when it gets out the machine, and some quantity of pieces was lost due the natural process of the segregation.

The information was obtained on standards at the product level according to the partial table. It shows the times used to process each piece, as well as different components of the standard (feeding time, electric test time and withdrawal time). In Table VI, the information mentioned in the Cycle Time column was used as the product standard. This serves to calculate the time, which each lot spent testing on the machine. In this table, the Product No column is dedicated to the part number, which corresponds to the standard; Pk Size shows the package geometry; Test Time denotes the electrical test cycle time; Index Time is the machine device feeding time; Threshold is the time, which corresponds to withdraw the test devices of the test tool; and Cycle time is the complete test time per piece. The information is also taken to calculate the test processing time of the product. The times are given in seconds.

TABLE VI
PRODUCT STANDARD

Product No	Pkg Size	Test Time	Index Time	Threshold	Cycle time
812-16	8.15x5.6	1.10	0.00	0.14	1.24
812-19	8.15x5.6	1.40	0.14	0.15	1.54
080-14	8.15x5.6	1.15	0.14	0.15	1.29

C. *Analysis of the scenarios to run*

To check the general sequencing model efficiency, three scenarios of a test run were defined according to the following:

1) Best Case - Only machines dedicated per part number were considered; the idle time caused by the lot change was only taken.
2) Worst Case – The machines are shared among families; every processed lot is taken with the family change idle time.
3) Proposed case - Minimal changes are considered to process the volumes ordered by the customer according to their priority and the part number.

Lot sequencing starts since calculating the processing duration of each lot (*Processed parts volume* x *Part number standard*), and the setup time is directly related to the lot change, recipe change, tool change or family change; it depends on the product lot sequence to process and the similarity between those lots.

To calculate the total processing time ($C_{\max}$), the start date on the electrical test was defined as January, 1- 2016 at 12:00 a.m, and the total of the processed lots was sequenced on the machine. The cumulated time to process the total quantity of lots for this period was calculated using the next formula:

$$C_{\max} = \sum_{f=1}^{F}\sum_{Pri=1}^{3}\sum_{m=1}^{M}\sum_{Prod=1}^{P}(Q_{f,Pri,m,Prod}\, x St_{f,Pri,Prod} + Lot\ setup_{f,Pri,m,Prod} \times Same\ PartNo + Recipe\ setup_{f,Pri,m,Prod} \times Different\ ContactMask + Tool\ setup_{f,Pri,m,Prod} \times Same\ ContactMask + Family\ setup_{f,Pri,m,Prod} \times Different\ geomerty) \rightarrow \min$$

where the notations used are:

Q – Quantity of pieces,
St – Standard processing time,
f – Family,
Pri – Priority,
m – Assigned machine,
Prod – Product or Part Number.

TABLE V
VOLUMES OF LOTS WITH PART NUMBER 812-19 FOR THE FAMILY WITH GEOMETRY 8.15X5.6

Lot	Part Number	Stage	Trackin Qty	Start Process Time	End Process Time	Equip Number	Trackout Qty
1413531.1	812-19	FUNC/TEST	7113	2016-01-01 00:13:18	2016-01-01 14:28:24	7DRG01	6836
1396044.1	812-19	FUNC/TEST	5486	2016-01-01 14:39:24	2016-02-01 01:59:17	7DRG01	4891
1406678.1	812-19	FUNC/TEST	6043	2016-01-02 02:09:06	2016-02-01 11:31:02	7DRG01	5971
1429238.1	812-19	FUNC/TEST	6769	2016-01-02 11:40:51	2016-03-01 23:32:21	7DRG01	6463

The setup type applied is dependent on the sequence of the previous product and of the next one on every machine. To note this, four Boolean variables are defined, which take the value 1 and multiply it by the value of the corresponding setup time in the case to be presented, if absent, take the value 0.

The name of variables and its definition are presented bellow:

Same PartNo – the previous part number in the sequence is the same;

Same ContactMask – the symmetry of the contactors in the next lot is the same;

Different ContactMask – the symmetry of the contactors in the next lot is different,

Different Geometry – the product geometry in the part number of the next lot is different.

Same PartNo, Same ContactMask, Different ContactMask, Different Geometry $\in \{0,1\}$.

The lot processing time and the setup time of each processed lot are considered, and only the family change is applied with a duration of approximately 210 minutes at the beginning of a monthly period. Table VII presents the lot processing time for family 8.15x5.6 per scenario; the amount is expressed in days.

TABLE VII
ANALYSIS OF TIME PER SCENARIO

Scenario	Start	Finish	CT (days)
Better	2016-01-01 00:00:00	2016-01-23 02:07:00	22.09
Worst	2016-01-01 00:00:00	2016-01-31 06:47:00	30.28
Proposed	2016-01-01 00:00:00	2016-01-23 12:07:00	22.50

In order to measure the efficiency of the general sequencing model and to compare the time gained or lost with moving from one scenario to another, a matrix was developed, where the time deviation expressed as Delta days is demonstrated, where Delta days represent the difference in days to move from the current scenario to another one. The information in Table VIII shows that in the case of moving from the proposed scenario to the best scenario, the difference is 0.42 days. The worst case scenario represents a family change for each lot processed in the factory. This means that the model, even though it is heuristic, is quite efficient as it is very close to the best result, assuming that all products being processed are equal.

TABLE VIII
RESULTS OF THE COMPARISON OF SCENARIOS EXPRESSED IN DELTA DAYS

Scenario	Best	Worst	Proposed
Better	0.00	-8.19	-0.42
Worst	8.19	0.00	-7.78
Proposed	0.42	7.78	0.00

In the same table, it is observed that the data present an additional improvement of 7.78 days per month, which means an increment 25.93 % of the installed capacity in the factory. Currently, the planner team has recognized 12% increment in the installed capacity, using the general sequencing model under real conditions. This practice of the planning at a family level can be spread to all families in the catalog and surely, better results will be achieved.

V. CONCLUSIONS

In a High tech semiconductor company, with characteristics of high volume – high mix, it is important to understand the product similarities. Planning without taking advantage of this fact leads to a myopia that complicates the efficient use of the installed capacity and setup in excess resulting in a downtime increase where machines are not productive. This work has put a foundation and structure for the planner to make a detailed short-term plan at the family level, to assign the required machines, to attend the product grouping into the families and to act quickly when a part number does not arrive as planned. In this case, it is clearly observed that there are major advantages of planning at the family level. As it was demonstrated, a gain of 25.93 % in the additional capacity was rescued from the operation, and it helps to reduce the discrepancies in the sequenced plan that make it difficult to enhance utilization of the installed capacity. Rescuing a quarter of the capacity, the company could attract more customers, produce more products, increase the delivered volume to customers and definitely reduce the operating cost, since machine depreciation is amortized in a greater volume of products, and this enhances the profitability for this semiconductor company.

This work helps as a first stage to develop a short term plan to continue with its optimization developing low cost efficient algorithms, which could be acceptable for a company with the characteristics previously mentioned. It is considered that the proposed model is exportable to any discrete manufacturing business, which has to sequence production orders.

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