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# Flow Customizer: A System that reveals how Mass Customization affects Continuous Flow Manufacturing

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**Abstract:** *Continuous Flow Manufacturing (CFM) is structured by Lean Thinking's pebbles, which derive from the Toyota Production System. It is widely known as an efficient production system. The scope of this paper is to examine this efficiency in a Mass Customization case. The Production Lines in Continuous Flow Manufacturing are usually Mixed Model Lines, such as Mixed Model Assembly Lines or Workcells. The product variability in Mixed Model Lines denotes a special appliance of Mass Customization (MC). Due to this variability, the current paper describes common aspects between CFM and MC under the notion of a practitioner. A procedure of production line design is described. It is named Flow Customizer™ (v.1). It unveils the connection between CFM and MC, reveals the problems between them and sets a design pattern for Production and Logistics in a MC environment. An application of the Flow Customizer is implemented in a conceptual production case for comprehension purpose.*

**Key Words***:* ***Continuous Flow Manufacturing, Lean Flow, Mass Customization, Flow Customizer™ (v.1), Modularization, Kanban***

## 1. INTRODUCTION

Production and Manufacturing Systems Design has a standard but also general framework that could be based on and many different versions are developed [1][2][3][4][5][6]. Layout Design is also in the same direction that can aid to the Production Design Phase [7][8]. The most famous as inquired layout problems are dealt with U or C workcells [9][10][11][12]. Mass Customization has set industry's challenges in a framework that is well described by the following sentence [13]:

*"The "focused factory" streamlined to produce a few carefully chosen products with high efficiency, remains the ideal for most manufacturing managers. This mentality leads to a "tradeoff" view of product variety. More variety is "good" because it increases revenue, but "bad" because it drives up production costs. Somewhere between Ford's vision of black for everybody and a fully customized product for each buyer lies the "optimal" level of product variety that trades off these good and bad effects".*

By following the aforementioned statement, the challenge of variety is seemed to be handled efficiently by Lean Manufacturing and Agile Production [14].

The "Flow Customizer" was represented as a term that describes a system for Image Processing in 2009 and it is irrelevant with the term of this work [15]. The Flow Customizer™ (v.1) is a path to engineer production line modules and connect them to each other. It customizes the operation flow during the engineering phase of a Continuous Flow Manufacturing System. It engineers and reengineers Production Line Modules for Mass Customization that operate in flow mode according to Continuous Flow Manufacturing essentials. The traditional approach to these Modules is to denote them as subassemblies. The subassemblies that are created by Flow Customizer™ (v.1.), follow fundamental aspects of modularization, such as the capability of dismantling the Modules and reengineer them in new framework from the beginning, creating a whole new system [16]. Modularization and Mass Customization consolidation is a challenging framework that is set on inquiry since many yeas [17][18]. Flexible and Numerically controlled machines or robots are developed to satisfy Mass Customization [19][20]. Reconfigurable Manufacturing Systems can also aid to Mass Customization [21][22][23]. Systems, such as Computer-aided Process Planning – CAPP, manages Resources and Production [24]. Flow Customizer™ (v.1.) manages the procedure of engineering and reengineering the system.

The second section represents by briefly explaining the steps of Flow Customizer™ (v.1). The third section describes an application with a paradigm. The fourth section summarizes conclusions and proposes future research opportunities.

## 2. THE FLOW CUSTOMIZER™

The contribution is denoted in the phase of Production Design. A method that customizes the production flow is developed for this purpose. The method is named Flow

Customizer™ (v.1) and designs flow production systems by creating Production Line Modules and connecting them to each other. The Production Line Modules are created to achieve high time efficiency. The connection to each other is achieved by implementing Kanban techniques. The Production Line Modules are mixed model production lines. The mixed-model production lines are considered to be close enough to Mass Customization business strategy. The hypothesis that builds the following system is based on author's PhD Dissertation [25]. Moreover, the fundamental assumption is that a mixed model production line can satisfy markets of Mass Customization. If the operations that build each product are appropriate, a mixed model line can efficiently apply Mass Customization. If the appropriate operations run in suitable portions of time, an efficient mixed model line can be created. The suitable time of the appropriate operations should follow demand pace, namely Takt time [26]. Demand pace should be followed by the production pace. This assumption is relevant to Lean Manufacturing. Production pace or demand pace is the metric that connects the appropriate operations of mixed model lines [27]. Efficient production pace in Lean Manufacturing can be established by value stream where materials and time operations "flow". Kanban System can connect mixed model lines to each other according to production pace, namely demand pace, and establish the desired flow [28]. Lean Flow is an integrated method that shapes the aforementioned assumptions and gives answers to the previous questions through its method [29]. The method is based on Demand Flow Technology tools and techniques of Designing Mixed Model Manufacturing Process and Logistics System for demand flow process [30][31]. Continuous Flow Manufacturing, Mass Customization and Lean Flow Method set the essentials of the Flow Customizer™. The representation with a brief explanation of each step of Flow Customizer™ follows. The Flow Customizer™ (v.1.) consists of 88 Steps that are grouped into 7 Phases. The Phases (Px) and their Steps (Sy) are described below. Each Step precedes another. The successor Steps are declared at the end of each predecessor Step. Some Steps are followed by two Steps simultaneously or separately. "Simultaneous" means that the Steps can start simultaneously and "separate" means that a decision step leads to operation or action steps, accordingly.

***P1: Initialization***: i = 1, m = 1, c = 1, j =1, p=1, n=1, s=1, k =1. $\rightarrow$S1.

**S1**: List all Materials Mm & their Quantities Qm per Product Pp, where m=1,2,...,m, & p=1,2,..,p (Bill of Materials [33]). $\rightarrow$S2.

**S2**: Define which materials are under customization as Mmc, where m=1,2,...m & c=1,2,...,c & Build their new BOMs, define their Quantities per Product Pp as $Qmc_{pi}$. The pointer i stands for Module i. $\rightarrow$S3.

**S3**: List all $AT_j$ & their precedencies (Bill of Processes or Operations – BOPs or BOOs [34]). Define their tasks as $T_j$, $tr_j$ and $Move_j$. j=1,2,…,j per product p. $\rightarrow$S4.

**S4**: Assign the materials into their $AT_j$ (from S2 Mmc to S3 $AT_j$), Mmc$\rightarrow T_j$ of $AT_j$, where m=1,2,...,m & c=1,2,...,c & j=1,2,...,j (Bill of Materials & Operations – BOMO [35]). $\rightarrow$S5.

**S5**: Name the tasks of customized products as $IP_j$, for every Mmc then $T_j \rightarrow IP_j$, where j=1,2,...,j & m=1,2,...,m & c=1,2,...,c. $\rightarrow$S6.

**S6**: Build Product Synchronization i, (define the precedence diagram of optional, rework, scrap and feeder processes). Sequence of Events is a tool that is used in Demand Flow Technology [30]. $\rightarrow$S7.

**S15**: Demand & Takt Time Definition. The following equation is used $Takt_i = \frac{H_i \times s_i}{Dc_i}$, where $H_i$ is the actual production time of one shift of Module i, $s_i$ the amount of shifts of Module i, and Demand at Capacity as $Dc_i = \sum_{p=1}^{p}(Dc_p \times Qmc_p)$, where $\sum_{p=1}^{p} Dc_{p_i} = Dc_{1_i} + Dc_{2_i} + \dots + Dc_{p_i}$, where p = 1,2,...,p denote products of Module i, $Qmc_p$ and $Dc_i$ is the daily production rate that Module i should achieve every day, namely every shift, once each day has one shift. $\rightarrow$S16.

***Phase 2 Analysis of Processes and Modules creation***,

**S7**: Is customization level satisfied? Are there enough options for customers? Yes$\rightarrow$S8, No$\rightarrow$S2.

**S8**: Exclude feeders and optional (if there are any) of Product Synchronization i from next steps and keep feeders and optional until to call them and then continue with there rest, i=i+1. $\rightarrow$S9.

**S9**: Call tasks and build Sequence of events i (time of every task and operation OPn). $\rightarrow$S10.

**S10**: Can NVA tasks be improved to VA? Yes$\rightarrow$S11, No$\rightarrow$S13.

**S11**: Waste minimization in operations
(Lean Techniques). $\rightarrow$S12.

**S12**: Build an Updated Sequence of events i. If there is one, otherwise continue. $\rightarrow$S13.

**S13**: Are all events included? (Gemba, Go and See). Yes$\rightarrow$S16, No$\rightarrow$S14.

**S14**: Delete i, j, n. $\rightarrow$S3.

**S16**: Build Process Map i, namely the table $[OP_{ni}, P_{pi}]_i$ for Module i, (products, processes, times, Resources, $\Sigma T_i$). Product/Process Map is a tool that is used in Demand Flow Technology [30]. The table is composed by Actual time of tasks j that belong to operation n that creates the product p in Module i and is calculated as $AT_{p\, n_i} = \sum_j (T_j + IP_j)_{p\, n_i}$, where j = 1,2,....j are the tasks, Tj is the time of task j, IPj is the time of interaction point task (interaction point is the task where customers customize their products), p = 1,2,…,p are the products and n = 1,2,...,n are the operations of Module i, i = 1,2,…i. The table is also composed by the Actual time weighted as follows $ATw_{n_i} = \frac{\sum_{p=1}^{p}(AT_{p\, n_i} \times Dc_{p\, n_i})}{Dc_{n_i}}$, where p = 1,2,…,p are the products and n = 1,2,...,n are the operations of Module i, i = 1,2,…i. The table is also composed by the number of Resources (operators and/or machines – robots etc.) weighted as follows $\#RESw_{n_i} = \frac{ATw_{n_i}}{Takt_{n_i}}$, where n = 1,2,...,n are the operations and Takt time is the $Takt_{n_i} = \frac{H_{n_i} \times s_{n_i}}{Dc_{n_i}}$ of Module i, where i = 1,2,…i and n = 1,2,...,n are the operations of Module i, $H_{in}$ is the production or operation time of one production shift, $s_{in}$ is the number of shifts that operate the operation n of Module i and Demand at Capacity of products p that are built by operations n, respectively as $Dc_{n_i} = \sum_{p=1}^{p} (Dc_{p_{n_i}} \times Qmc_{p_{n_i}})$, where $\sum_{p=1}^{p} Dc_{p_{n_i}} = Dc_{1\,n_i} + Dc_{2\,n_i} + ... + Dc_{p\,n_i}$, where each $Dc_{p\ n}$ of Module i should refers to operation n only if production time of operation n is not zero, namely stands $AT_{p\ ni} \neq 0$. The number of Resources per product p is given by $\# RES_{p_i} = \frac{\sum_{n=1}^{n} AT_{p\,n_i}}{Takt_i}$. → S17.

**S17**: Are there any product - material that its #RES is not equal to #RESw? (Economies of scope). Is the following valid? $\# RES_{p_i} = \sum_{n=1}^{n} \# RESw_{n_i}$.
If yes, then the specific product p remains to Module i by the next step. Yes → S18, No → S24.

**S18**: Choose and extract products from Process Map i. The product selection can be achieved by the following rule $\sum_{n=1}^{n} \# RESw_{n_i} \times 0,7 < \# RES_{p_i} < \sum_{n=1}^{n} \# RESw_{n_i} \times 1,1$ that is used in Lean Flow or by any relevant heuristic algorithm that minimizes the number of selected products that are going to extract from Module i. This optimization challenge tries to satisfy Economies of Scope, namely it should be the more products in less but also efficiently balanced Modules. → S19 and S20. This denotes that S19 and S20 can start simultaneously after the completion of S18.

**S19**: Choose the remain Process Map i & update its Product Synchronization i. → S17.

**S20**: Choose the rest and Build new Product Synchronization i=i+1 & Process Map i=i+1. → S21.

**S21**: Can all products be redesigned? Yes → S22, No → S23.

**S22**: Define those products of Process Map i and check Product Design for Mass Customization. → *P1*.

**S23**: Is there any product left in Process Map i from S20? Yes → S17, No → S19.

**S24**: Is $Takt_i$ less than min {T1,T2,..Tj} of $OPn_i$? Namely, is the following valid?

$$Takt_i < \max \left\{ \begin{array}{l} \min\left\{ T_{j_{1\,1}} + IP_{j_{1\,1}}\ ,\ T_{j_{1\,2}} + IP_{j_{1\,2}}, ..., T_{j_{1\,n}} + IP_{j_{1\,n}} \right\}_1 , \\ \min\left\{ T_{j_{2\,1}} + IP_{j_{2\,1}}\ ,\ T_{j_{2\,2}} + IP_{j_{2\,2}}, ..., T_{j_{2\,n}} + IP_{j_{2\,n}} \right\}_2 , \\ ..., \\ \min\left\{ T_{j_{p\,1}} + IP_{j_{p\,1}}\ ,\ T_{j_{p\,2}} + IP_{j_{p\,2}}, ..., T_{j_{p\,n}} + IP_{j_{p\,n}} \right\}_p \end{array} \right\}_i$$

Yes → S25, No → S26.

**S25**: Add Production shifts s or actual production time H or number of Resources. → S15.

**S26**: Group each previous work & name it as Module i. → S27.

**S27**: Wait until all Modules reach here. → S28.

**S28**: Call Product Synchronization i with the less operations. → S29.

**S29**: Are there any optional left in S8? Yes → S30, No → S31.

**S30**: Choose upstream the first longest of the remaining optional and i=i+1. → S6.

**S31**: Are there any feeders left in S8? Yes → S32, No → S33.

**S32**: Choose upstream the first longest of the remaining feeders and i=i+1. → S6.

**S33**: Is there any other Product Synchronization left in S26? Yes → S28, No → S34.

**S34**: Categorize Modules into Assembly Lines, Workcells, Single Machines or Operations and Suppliers/warehouses. → S35.

**S35**: Do modules have the same pace? Is one-piece flow in Takt time applied? Yes → S36, No → S37.

**S36**: Connect Modules directly to each other using IPKs technique & one piece-flow. Value Stream Mapping (VSM) can be used. → S38 and S51. This denotes that S38 and S51 can start simultaneously after the completion of S36 or S37.

**S37**: Connect Modules upstream to each other through Decoupling Points (Supermarkets), picture it in a VSM (Kanban, IPKs, Suppliers, Warehouses), Define all DPs. → S38 and S51. This denotes that S38 and S51 can start simultaneously after the completion of S37 or S36.

***Phase 3 Module Balancing,*** **S38**: Is Module i an Assembly Line? Yes → S39, No → S42.

**S39**: Is Module balancing efficient in Takt time? (Is $ATw_{ni} = Takt_{ni}$?). Yes → S45, No → S40.

**S40**: Rearrange tasks to adjacent Operations for better efficiency. → S41.

**S41**: Is Module balancing efficient in Takt time? (Is $ATw_{ni} = Takt_{ni}$?). Yes → S45, No → S42.

**S42**: Add IPKs technique. → S43.

**S43**: Is Module balancing efficient in Takt time? (Is $ATw_{ni} = Takt_{ni}$?). Yes → St45, No → S44.

**S44**: Add resources where $ATw_{ni} > Takt_{ni}$. → S45.

***Phase 4 Operation Balancing,*** **S45**: Product Complementarity for Operation balancing on time, Check Just in Sequence ability. → S46.

**S46**: Are Operations efficient balanced for mixed model in Takt time? Is the following valid? $\frac{\sum_{p=1}^{p} AT_{p_i}}{\text{Utilized Resources}} = Takt_i$. Yes → S50, No → S47.

**S47**: Add IPKs technique. → S48.

**S48**: Are Operations efficient balanced for mixed model in Takt time? Is the equation in S46 valid? Yes → S50, No → S49.

**S49**: Add resources. → S50.

**S50**: Draw Production Layout (for Modules). → S86.

***Phase 5 Modules Connection (Logistics),*** **S51**: In VSM, start from the first upstream Module i and choose the first upstream DPs of the line for designing pull sequence or push methods. → S52.

**S52**: Define the materials that located in DPs with materials Mmc & Mm, (DPs ← Mmc, DPs ← Mm). → S53.

**S53**: Define capable materials in DPs for JIT handling, (80/20 Pareto rule) [36]. → S54.

**S54**: Is the material Mmc approved for JIT handling in DPs? (Classification X, Y and Z ⇒ σ≤μ, under circumstances). Yes → S55, No → S71.

**S55**: Use signal techniques (Kanban) for each capable material, choose material Mmc. → S56.

**S56**: Is DPs's material Mmc replenished by Assembly Line Modules? Kpmci is renamed into Kpalmci if Module i is an Assembly Line, Kpcmci if it is a Workcell, Kpsmmci if it is a Single Machine and Kpsmci if it is a Supplier. Yes → S57, No → S58.

**S57**: Name & Calculate Production Kanban $Kpalmc_i$ of Assembly Line Module i. (Calculate Assembly Line's $Ralmc_i$). The following calculations are also used by Demand Flow Technology [31].

$$Kalm_{c_i} = \frac{\sum_{j=1}^{j}(tr_{j_{p\,n}} + T_{j_{p\,n}} + IP_{j_{p\,n}})_i}{Takt_i - \min\left\{T_{j_{p\,n}} + IP_{j_{p\,n}}\right\}_i}$$

and

$$Ralm_{c_i} = \sum_{j=1}^{j}(tr_{j_{p\,n}} + T_{j_{p\,n}} + IP_{j_{p\,n}})_i + \min\left\{T_{j_{pn}} + IP_{j_{p\,n}}\right\}_i \times (Kalm_{c_i} - 1)$$

, where

$$IP_{j_{p\,n}} = \begin{cases} \text{interaction point at task j, in operation n, for product p and } T_{j_{p\,n}} = 0 \\ 0 \text{ and } T_{j_{p\,n}} \neq 0 \text{ Otherwise} \end{cases}$$

, mc is the customized version c of material m, trjp n is the setup time of task j of operation n that build product p, Tjp n ή IPjp n is the actual time, Takti is the Takt time of Module I that operation n belongs to. → S63.

**S58**: Is DPs's material Mmc replenished by Workcell Modules? Yes → S59, No → S60.

**S59**: Name & Calculate Production Kanban $Kcmc_i$ of Workcell Module i. (Calculate Workcell's $Rcmc_i$) [31].

$$Kcm_{c_i} = \frac{\sum_{j=1}^{j}(tr_{j_{p\,n}} + T_{j_{p\,n}} + IP_{j_{p\,n}})_i}{Takt_i - \min\left\{T_{j_{p\,n}} + IP_{j_{p\,n}}\right\}_i}$$

and

$$Rcm_{c_i} = \sum_{j=1}^{j}(tr_{j_{p\,n}} + T_{j_{p\,n}} + IP_{j_{p\,n}})_i + \min\left\{T_{j_{p\,n}} + IP_{j_{p\,n}}\right\}_i \times (Kcm_{c_i} - 1)$$

, where

$$IP_{j_{p\,n}} = \begin{cases} \text{interaction point at task j, in operation n, for product p and } T_{j_{p\,n}} = 0 \\ 0 \text{ and } T_{j_{p\,n}} \neq 0 \text{ Otherwise} \end{cases}$$

and the rest variables are the same to *P5*, S57. → S63.

**S60**: Is DPs's material Mmc replenished by Single Machine Modules? Yes → S61, No → S62.

**S61**: Name & Calculate Production Kanban $Ksmmc_i$ of Single Machine Module i. (Calculate Single Machine's $Rsmmc_i$) [31].

$$Ksmm_{c_i} = \frac{tr_{j_{p\,n_i}}}{Takt_i - T_{j_{p\,n_i}}}$$

and

$$Rsmm_{c_i} = tr_{j_{p\,n_i}} + T_{j_{p\,n_i}} \times Ksmm_{c_i}$$

, where

$$T_{j_{p\,n_i}} = \begin{cases} IP_{j_{p\,n_i}} & \text{if task j, in operation n, for product p is an interaction point} \\ T_{j_{p\,n_i}} & \text{Otherwise} \end{cases}$$

and the rest variables are the same to *P5*, S57. → S63.

**S62**: Calculate Supplier Kanban $Ksmc_i$ of Supplier Module i. (Calculate Supplier's $Rsmc_i$ - VMI & PR). The following is valid

$$Ksm_{c_i} \times Takt_{n_i} = Ksm_{c_i} \times Lt_i + Dt_i + Ksm_{c_i} \times (1 - reliability\%_i) + Ksm_{c_i} \times SS\%_i$$

so

$$Ksm_{c_i} = \frac{Dt_i}{Takt_{n_i} - Lt_i - 1 + reliability\%_i - SS\%_i}$$

and

$$Rsm_{c_i} = Dt_i + Ksm_{c_i} \times (Lt_i + 1 - reliability\%_i + SS\%_i)$$

, where mc is the customized version c of material m, Dti is the distribution time of material mc from the supplier i, Taktni is the Takt time of operation n where material mc will be consumed, Lti is the Lead time of supplier i of material mc, reliability% is a possible factor that express supplier's reliability and SS% is a possible Safety Stock that is wise to be kept. → S63.

**S63**: Do Kanbans feed an Assembly Line? The following is valid [31]:

$$Kwm_{c_i} = \frac{Dc_{p_i} \times Qm_{c_{p_i}} \times Rm_{c_i}}{H_{n_i} \times Pm_{c_i}}$$

, where $mc_i$ is the customized version c of material m that is delivered to Module i in quantities of Kwmci , Dcpi and Qmcpi are defined in *P1*, S15, Rmci is defined in *P5*, S63 and also by previous steps, Hni is defined by previous steps and Pmci is the batch or packaging size for materials that are produced or delivered in such a way. Kwmci is renamed into Kwalmci if Module i is an Assembly Line, Kwcmci if it is a Workcell, Kwsmmci if it is a Single Machine and Kwsmci if it is a Supplier. Rmci is renamed into Ralmci if Module i is an Assembly Line, Rcmci if it is a Workcell, Rsmmci if it is a Single Machine, Rsmci if it is a Supplier. Yes → S64, No → S65.

**S64**: Name & Calculate Withdrawal Kanban $Kwalmc_i$. (Use Assembly Line's $Ralmc_i$). → S72.

**S65**: Do Kanbans feed a Workcell? Yes → S66, No → S67.

**S66**: Name & Calculate Withdrawal Kanban $Kcmc_i$. (Use Workcell's $Rcmc_i$). → S72.

**S67**: Do Kanbans feed a Single Machine? Yes → S68, No → S69.

**S68**: Name & Calculate Withdrawal Kanban $Ksmmc_i$. (Use Single Machine's $Rsmmc_i$). → S72.

**S69**: Do Kanbans feed a Customer? Yes → S70, No → S71.

**S70**: Name & Calculate Withdrawal Kanban $Ksmc_i$. (Use Supplier's $Rsmc_i$). → S72.

**S71**: Choose material mc, use special handling techniques, (Min/Max, Breadtruck) [37]. → S79.

**S72**: Define Kanbans' point of use in Modules & in DPs between Modules. → S73.

**S73**: Can at least 2 containers share the quantity of Withdrawal Kanban of Mmc? Yes → S74, No → S75.

**S74**: Connect Module i & DPs with One Kanban card & Dual Container. → S76.

**S75**: Share Kanban Quantity into containers using Multiple Cards & Calculate their number (+1) & Connect Module i & DPs [31].

$$Ncards_{mc_{i \to s \to i}} = roundup\left(\frac{Kpm_{c_i}}{Kwm_{c_i}}\right) + 1$$

. → S76.

**S76**: Does Module i consist of more than two Mixed Model Operations? Is n > 2 in OPn of i? Yes → S78, No → S77.

**S77**: Use Kanban & FIFO one-piece flow between operations of Module i. → S79.

**S78**: Use ConWIP Kanban & FIFO one-piece flow between operations of Module i [38]. → S79.

**S79**: Is there any other material in DPs (Supermarket)? Yes → S80, No → S81.

**S80**: Next Material of DPs, m = m + 1 & c = c + 1 till to choose one. → S54.

**S81**: Is there any other upstream DPs (Supermarket)? Yes → S82, No → S83.

**S82**: s = s + 1. → S51.

**S83**: Are all materials covered for handling? (Gemba, Go and See). Yes → S85, No → S84.

**S84**: Delete all & Start Over. (Delete i,m,c,j,p,n,s,k). →*P1*.
**S85**: Draw DP Layout (for Materials). →S86.
***Phase 6 Gathering Data,*** **S86**: Are all data for Modules and DPs gathered? Yes→S88, No→S87.
**S87**: Wait until all data pass through here. →S83.
***Phase 7 Summarize results and draw Production Layout & Decoupling Points,*** **S88**: Integrate & Draw Production Layout & Decoupling Points.

## 3. APPLICATION OF FLOW CUSTOMIZER™

This section represents a paradigm of Flow Customizer v.1. The paradigm is implemented in a conceptual production case. Each step is stated below of each table, figures or calculations to give a better comprehension of the Flow Customizer™ (v.1)'s function. Tables and figures can be used by more than one step. The paradigm designs a system that can produce 4 final products and 20 of their materials. Some of them can also be delivered by suppliers. The 20 materials build the four products according with their BOM. The paradigm describes the function until the creation of Module 5. The rest are created by the same procedure. All the possible situations and Flow Customizer™ (v.1)'s options are satisfied till Module 5 is created. The results are gathered into tables 4, 5, 14, 16, 17, 19 and figures 7 and 9.

Table 1 and Table 2 give the input data of Materials and Tasks that build them, namely Bill of Materials and Bill of Processes. Figure 1 and 2 give the schematically concept of BOM and BOP, respectively.

Table 1. *Bill of (under customization) Materials data – BOMs data*

| Product | Material | Level | | | | | Construct |
|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | … | |
| **P1-> P1** | | 1 | | | | | |
| | M1 | | 1 | | | | P1 |
| | M2 | | 1 | | | | P1 |
| | M9 | | 2 | | | | P1 |
| | M3 | | | 2 | | | M2 |
| | M4 | | | 1 | | | M2 |
| **P1-> P2** | | 1 | | | | | |
| | M10 | | 4 | | | | P2 |
| | M21 | | 1 | | | | P2 |
| | M11 | | 1 | | | | P2 |
| **P1-> P3** | | 1 | | | | | |
| | M11 | | 2 | | | | P3 |
| | M12 | | 1 | | | | P3 |
| | M22 | | 1 | | | | P3 |
| | M32 | | | 2 | | | M22 |
| | M42 | | | 1 | | | M22 |
| **P2-> P4** | | 1 | | | | | |
| | M13 | | 1 | | | | P4 |
| | M5 | | 1 | | | | P4 |
| | M31 | | 1 | | | | P4 |
| | M6 | | | 1 | | | M5 |
| | M7 | | | 1 | | | M5 |
| | M8 | | | 2 | | | M5 |
| | M31 | | | | 2 | | M8 |
| **Pp** | Mmc | Qmc | Qmc | Qmc | Qmc | ... | ... |

*P1*, S1 and S2.

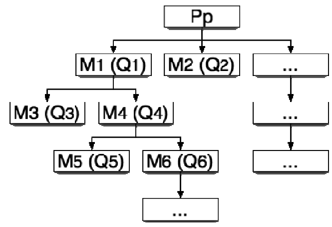


Fig. 2. *Bill of Materials – BOMs*

Table 2. *Bill of Operations and Materials data – BOMO data*

| Product | AT | Level | Predecessors | tr, T or IP, Move (min.) | Construct |
|---|---|---|---|---|---|
| **P1** | AT1 | 1 | | 40, 17, 110 | M9 |
| | AT2 | 0 | AT1, AT4 | 30, 18, 120 | P1 |
| | AT3 | 0 | AT2, AT6 | 40, 13, 10 | P1 |
| | AT4 | 1 | AT5 | 30, 40, 20 | M1 |
| | AT5 | 1 | | 30, 100, 20 | M1 |
| | AT6 | 1 | AT7, AT8, | 40, 20, 30 | M2 |
| | AT7 | 2 | | 50, 17, 30 | M3 |
| | AT8 | 2 | | 40, 22, 120 | M4 |
| | AT17 | 2 | AT18 | 30, IP17=30, 20 | M41 |
| | AT18 | 2 | | 50, IP18=30, 50 | M41 |
| **P2** | AT9 | 1 | | 30, 7, 40 | M10 |
| | AT10 | 0 | AT9, AT12 | 20, 16 , 60 | P2 |
| | AT11 | 0 | AT10, | 30, 14, 60 | P2 |
| | AT12 | 1 | AT13 | 50, IP12=70, 60 | M11 |
| | AT13 | 1 | | 40, IP13=20, 60 | M11 |
| | AT14 | 1 | AT15 | 70, IP14=60, 90 | M21 |
| | AT15 | 1 | | 40, IP15=20, 120 | M21 |
| **P3** | AT19 | 1 | | 60, 22, 20 | M11 |
| | AT20 | 0 | AT19, | 50, 40, 20 | P3 |
| | AT21 | 0 | AT24, | 40, 70, 20 | P3 |
| | AT22 | 1 | AT23 | 30, IP22=40, 60 | M12 |
| | AT23 | 1 | | 40, IP23=50, 200 | M12 |
| | AT24 | 1 | AT26, | 30, IP24=90, 50 | M22 |
| | AT25 | 2 | | 10, IP25=50, 200 | M32 |
| | AT26 | 2 | AT25 | 90, IP26=70, 120 | M32 |
| | AT27 | 2 | | 90, IP27=12, 110 | M42 |
| **P4** | AT28 | 0 | | 80, 14, 20 | P4 |
| | AT29 | 0 | AT28, | 20, 17, 40 | P4 |
| | AT30 | 1 | AT33, | 40, 24, 20 | M5 |
| | AT31 | 1 | | 30, IP31=50, 200 | M13 |
| | AT32 | 1 | AT31 | 10, IP32=80, 200 | M13 |
| | AT33 | 2 | | 20, 16, 50 | M6 |
| | AT34 | 2 | | 50, 20, 150 | M7 |
| | AT35 | 2 | AT34 | 100, 50, 120 | M7 |

| | | | | | |
|---|---|---|---|---|---|
| | AT36 | 2 | AT16 | 150, 19, 20 | M8 |
| | AT16 | 3 | | 130, IP16=13, 20 | M31 |
| **Pp** | ATj | ... | ... | trj, Tj / IPj, Movej | ... |

*P1*, S3, S4 and S5.

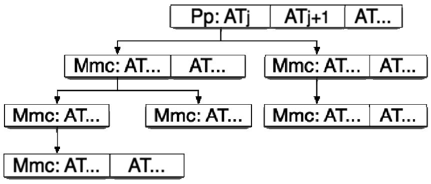


Fig. 3. *Bill of Operations and Materials - BOMO*

Figure 4 displays the sequence of tasks that build Products P1, P2, P3 and P4. The sequence of tasks is named Product Synchronization and each product has its own. The target is to form one common Product Synchronization from the rest, as it is displayed by Product Synchronization 1, below. The next steps assess each task per product for time efficiency and extract them from Product Synchronization 1 and build new Product Synchronizations. Figure 4 gives data to Table 3. Table 3 groups the tasks into classes that will be used by following steps. Classes are created upstream of the flow.

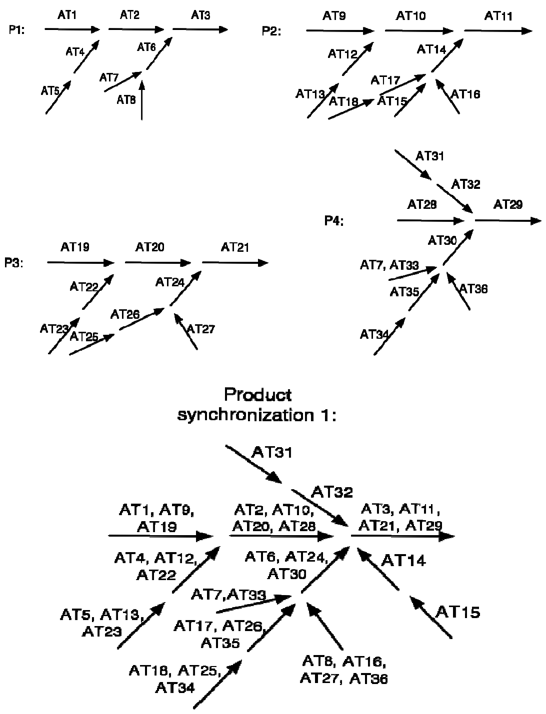


Fig. 4. *Product Synchronization design and Product Synchronization 1*

*P1*, S6.

Table 3. *Upstream classification of Tasks according to Product Synchronization design*

| Classification (upstream) | Tasks Group |
|---|---|
| Main (1st Module under examination) | AT2 - AT3, AT10 - AT11, AT20 - AT21, AT28 - AT29 |
| Optional to Main: | AT1, AT9, AT19 |
| Feeders to Main: | AT31 - AT32 |
| Feeders to Main: | AT15 - AT14 |
| Feeders to Main: | AT6, AT24, AT30 |
| Optional to Feeders: | AT7, AT33 |
| Feeders to Feeders: | AT18 - AT17, AT25 - AT26, AT34 - AT35 |
| Feeders to Feeders: | AT8, AT16, AT27, AT36 |
| Feeders to Main: | AT5 - AT4, AT13 - AT12, AT23 - AT22 |

*P2*, S8, S29.

The Demand at Capacity of each product is calculated as follows, where Monthly workdays = 19,33, see below Table 4. It gives the amount of products or materials that the production system should produce. The technique of estimation is not the ideal but only a proposed one.

Table 4. *Demand at Capacity per product*

| Product | μp : Mean Demand per Month | σp : Standard Deviation | Dcp per Day |
|---|---|---|---|
| P1 | 102.34 | 71.638 | 9.0004 ≈ 9 |
| P2 | 243.66 | 46.2954 | 15.0003 ≈ 15 |
| P3 | 59.94 | 17.3826 | 4.0001 ≈ 4 |
| P4 | 95.29 | 40.0218 | 7.00009 ≈ 7 |
| Pp | μp | σp | $Dc_p = \frac{\mu_p + \sigma_p}{\text{Monthly workdays}}$ |

The Demand Capacity of each material, which builds the four products above, is given by the following table.

Table 5. *Demand at Capacity per material*

| Product | Dcp per Day | Qmcp | Dc Material per Day per Module |
|---|---|---|---|
| M9 | 9 | 2 | 18 |
| M10 | 15 | 4 | 60 |
| M11 | 4 | 2 | 8 |
| M13 | 7 | 1 | 7 |
| M21 | 15 | 1 | 15 |
| M2 | 9 | 1 | 9 |
| M22 | 4 | 1 | 4 |
| M5 | 7 | 1 | 7 |
| M3 | 9 | 2 | 18 |
| M6 | 7 | 1 | 7 |
| M41 | 15 | 1 | 15 |
| M7 | 7 | 1 | 7 |
| M32 | 4 | 2 | 8 |
| M4 | 9 | 1 | 9 |
| M8 | 7 | 2 | 14 |
| M31 | 15 | 2 | 30 |
| M42 | 4 | 1 | 4 |
| M11 | 15 | 1 | 15 |
| M12 | 4 | 1 | 4 |
| M1 | 9 | 1 | 9 |
| Dci | Dcp | Qmcp | $Dc_i = \sum_{p=1}^{p} (Dc_p \times Qmc_p)$ |

*P1*, S15.

Before Sequence of Events 2, all the data are gathered in SOE 1 that represent data of all products and materials. It is logic assumption that Products should be studied separately from Materials. So, SOE 2 concludes the tasks of all the four Products. This is the first class of Table 3. It supports the importation of Lean Manufacturing's value. In these steps, non-value adding tasks are cancelled and waste time is diminished by Lean Techniques implementation (Single Exchange of Die, Transportation decrease, etc.) The time of SOE is used in next steps that form Process Maps.

Table 6. *Sequence of Events - SOE 2 for Module 2*

| Taskk p j | VA | NVA | Set-up (min.) | Actual (min.) | Move (min.) | Quality Control | $\sum_k T_{k\,p\,j}$ |
|---|---|---|---|---|---|---|---|
| Task1 1 2 | | χ | 30 | | | | |
| Task2 1 2 | χ | | | 18 | | χ | |
| Task3 1 2 | | χ | | | 120 | | 168 |
| Task4 1 3 | | χ | 40 | | | | |
| Task5 1 3 | χ | | | 13 | | | |
| Task6 1 3 | | χ | | | 10 | | 63 |
| Task7 2 10 | | χ | 20 | | | | |
| Task8 2 10 | χ | | | 16 | | χ | |
| Task9 2 10 | | χ | | | 60 | | 96 |
| Task10 2 11 | | χ | 30 | | | | |
| Task11 2 11 | χ | | | 14 | | | |
| Task12 2 11 | | χ | | | 60 | | 104 |
| Task13 3 20 | | χ | 50 | | | | |
| Task14 3 20 | χ | | | 40 | | χ | |
| Task15 3 20 | | χ | | | 20 | | 110 |
| Task16 3 21 | | χ | 40 | | | | |
| Task17 3 21 | χ | | | 70 | | | |
| Task18 3 21 | | χ | | | 20 | | 130 |
| Task19 4 28 | | χ | 80 | | | | |
| Task20 4 28 | χ | | | 14 | | χ | |
| Task21 4 28 | | χ | | | 20 | | 114 |
| Task22 4 29 | | χ | 20 | | | | |
| Task23 4 29 | χ | | | 17 | | | |
| Task24 4 29 | | χ | | | 40 | | 77 |
| | | | | | | | |
| $\sum_{k=1}^{24} T_k$ | | | 310 | 202 | 350 | | |

*P2*, S9, S10, S11 and S12.

The Process Map 1 concludes the four Products and the twenty Materials and is not displayed in this work, but the Process Map 2 studies only the four Products in the logic that is mentioned for SOE 2. The first class of Table 3 denotes the tasks that should be studied. These tasks build the four products. So, Process Map 1 is not necessary to be displayed. The following study shows that Product 3 of Module 2 ($P3_2$) do not satisfies the rule of Step 18, so it is extracted from Module 2. Module 2 is restudied with only the three remained products. They satisfy the rule so Module 2 will produce the three products, see figure 5 and table 8.

Table 7. *Process Map 2 for Module2 before Economies of Scope*

| Module 2 | OP12 | OP22 | Control |
|---|---|---|---|
| Ppi | $AT_{p_i} = \sum_j (T_j + IP_j)_{p1_i}$ | | $\#RES_{p_i}$ |
| $P1_2$ | AT2=18 min. | AT3=13 min. | 2,41 |
| $P2_2$ | AT10=16 min. | AT11=14 min. | 2,33 |
| $P3_2$ | AT20=40 min. | AT21=70 min. | 8,55 |
| $P4_2$ | AT28=14 min. | AT29=17 min. | 2,41 |
| | | | |
| $Dc_{n_i}$ | 35 pcs. | 35 pcs. | $Dc_{n_i}$ |
| $ATw_{n_i}$ | 18,86 min. | 20,74 min. | $\frac{\sum_{p=1}^{p}(AT_{pn_i} \times Dc_{pn_i})}{Dc_{n_i}}$ |
| $Takt_{n_i}$ | 12,86 min. / piece | 12,86 min. / piece | $\frac{H_{n_i} \times s_{n_i}}{Dc_{n_i}}$ |
| $\#RESw_{n_i}$ | 1,47 | 1,56 | $\frac{ATw_{n_i}}{Takt_{n_i}}$ |

*P2*, S16.

After product $P3_2$'s extraction from Module 2, SOE 2 should be updated, see below figure 5.

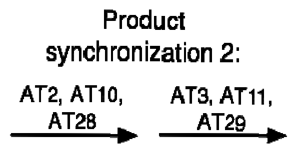


Fig. 5. *Product Synchronization 2 for Module 2 before Economies of Scope*

*P2*, S19.

Table 8. *Process Map 2 of Module 2 after Economies of Scope*

| Module 2 | OP12 | OP22 | Control |
|---|---|---|---|
| Ppi | $AT_{p_i} = \sum_j (T_j + IP_j)_{p1_i}$ | | $\#RES_{p_i}$ |
| $P1_2$ | AT2=18 min. | AT3=13 min. | 2,13 |
| $P2_2$ | AT10=16 min. | AT11=14 min. | 2,06 |
| $P4_2$ | AT28=14 min. | AT29=17 min. | 2,13 |
| | | | |
| $Dc_{n_i}$ | 31 pcs. | 31 pcs. | $Dc_{n_i}$ |
| $ATw_{n_i}$ | 16,13 min. | 14,39 min. | $\frac{\sum_{p=1}^{p}(AT_{pn_i} \times Dc_{pn_i})}{Dc_{n_i}}$ |
| $Takt_{n_i}$ | 14,51 min. / piece | 14,51 min. / piece | $\frac{H_{n_i} \times s_{n_i}}{Dc_{n_i}}$ |
| $\#RESw_{n_i}$ | 1,11 | 0,99 | $\frac{ATw_{n_i}}{Takt_{n_i}}$ |

*P2*, S17, Process Map 2. *P3*, S39, S44.

The procedure chooses the remain Product 3 and studies for a new Module 3 that will produce this product. The Product 3 from $P3_2$ is renamed into $P3_3$. The Product Synchronization 3 consists of AT20 and AT21 and Process Map 3 is given in Table 9.
*P2*, S20.

Table 9. *Process Map 3 for Module 3*

| Module 3 | OP13 | OP23 | Control |
|---|---|---|---|
| $P3_3$ | AT20=40 min. | AT21=70 min. | 0,44 |
| | | | |
| $Dc_{n_i}$ | 4 pcs. | 4 pcs. | $Dc_{n_i}$ |
| $ATw_{n_i}$ | 40 min. | 70 min. | $\frac{\sum_{p=1}^{p}(AT_{pn_i} \times Dc_{pn_i})}{Dc_{n_i}}$ |
| $Takt_{n_i}$ | 112,5 min. / piece | 112,5 min. / piece | $\frac{H_{n_i} \times s_{n_i}}{Dc_{n_i}}$ |
| $\# RESw_{n_i}$ | 0,36 | 0,62 | $\frac{ATw_{n_i}}{Takt_{n_i}}$ |

*P2*, S20, Process Map 3, Module 3. *P3*, S39, S44.

The next class of Table 3 gives the next Module 4 that is studied as the previous one. Its Product Synchronization, SOE and Process Map follow. The steps are the same to the previous because the function loops until all the Products and Materials are chosen. Product Synchronization 4 consists of AT1, AT9 and AT19.

Table 10. *Sequence of events 4 for Module 4*

| Taskk p j | VA | NVA | Set-up (min.) | Actual (min.) | Move (min.) | Quality Control | $\sum_k T_{kpj}$ |
|---|---|---|---|---|---|---|---|
| Task1 1 1 | | χ | 40 | | | | |
| Task2 1 1 | χ | | | 17 | | χ | |
| Task3 1 1 | | χ | | | 110 | | 167 |
| Task4 2 9 | | χ | 30 | | | | |
| Task5 2 9 | χ | | | 7 | | χ | |
| Task6 2 9 | | χ | | | 40 | | 77 |
| Task7 3 19 | | χ | 60 | | | | |
| Task8 3 19 | χ | | | 22 | | χ | |
| Task9 3 19 | | χ | | | 20 | | 102 |
| | | | | | | | |
| $\sum_{k=1}^{9} T_k$ | | | 130 | 46 | 170 | | |

The following study shows that Material 10 that build Product 2 of Module 4 ($P2_4$:M10) do not satisfies the rule of S18, so it is extracted from Module 4. Module 4 is restudied with only the two remained materials. They satisfy the rule so Module 4 will produce the two products, by the updated Product Synchronization 4 with AT1 and AT19 and Process Map 4 see Table 11.

Table 11. *Process Map 4 for Module 4*

| Module 4 | OP14 | Control |
|---|---|---|
| Ppi:Mmc | $AT_{p_i} = \sum_j (T_j + IP_j)_{p1_i}$ | $\# RES_{p_i}$ |
| $P1_4$:M9 | AT1=17 min. | 3,24 |
| $P2_4$:M10 | AT9=7 min. | 1,33 |
| $P3_4$:M11 | AT19=22 min. | 4,2 |
| | | |
| $Dc_{n_i}$ | 86 pcs. | $Dc_{n_i}$ |
| $ATw_{n_i}$ | 10,49 min. | $\frac{\sum_{p=1}^{p}(AT_{pn_i} \times Dc_{pn_i})}{Dc_{n_i}}$ |
| $Takt_{n_i}$ | 5,2 min. / piece | $\frac{H_{n_i} \times s_{n_i}}{Dc_{n_i}}$ |
| $\# RESw_{n_i}$ | 2 | $\frac{ATw_{n_i}}{Takt_{n_i}}$ |

The following is valid for Module 4 in Equation of *P2*, S24: Takt4 < Task193 1 $\Rightarrow$ 17.3 < 22, then S25. One more shift is chosen to be added in Module 4 due to the previous rule in S24, so $s_4 = s1_4 = 2$ shifts and the $Takt_4$ of Module 4 is calculated as follows: Equation of *P1*, S15, where i = 4, H4 = 450 min., s4 = 2 and Dc4 = 26 pcs. So, Takt4 = 34,6 min./piece. The results of adding one more shift are causing no any change for Product Synchronization 4, but the Process Map 4 needs to be updated, see below Table 12:

Table 12. *Process Map 4 for Module 4 after adding one more shift*

| Module 4 | OP14 | Control |
|---|---|---|
| Ppi:Mmc | $AT_{p_i} = \sum_j (T_j + IP_j)_{p1_i}$ | $\# RES_{p_i}$ |
| $P1_4$:M9 | AT1=17 min. | 0,98 |
| $P3_4$:M11 | AT19=22 min. | 1,27 |
| | | |
| $Dc_{n_i}$ | 26 pcs. | $Dc_{n_i}$ |
| $ATw_{n_i}$ | 18,54 min. | $\frac{\sum_{p=1}^{p}(AT_{pn_i} \times Dc_{pn_i})}{Dc_{n_i}}$ |
| $Takt_{n_i}$ | 34,6 min. / piece | $\frac{H_{n_i} \times s_{n_i}}{Dc_{n_i}}$ |
| $\# RESw_{n_i}$ | 0,54 | $\frac{ATw_{n_i}}{Takt_{n_i}}$ |

*P2*, S20, Process Map 4, Module 4. *P3*, S39. *P3*, S44.

The procedure chooses the remain Material 10 and studies for a new Module 5 that will produce this material. Product Synchronization 5 consists of AT9 and the Process Map 5 is displayed by Table 13. The Material 10 is renamed into $P2_5$:M10.

Table 13. *Process Map 5 for Module 5*

| Module 5 | OP15 | Control |
|---|---|---|
| $P2_5$:M10 | AT9=7 min. | 0,93 |
| | | |
| $Dc_{n_i}$ | 60 pcs. | $Dc_{n_i}$ |
| $ATw_{n_i}$ | 7 min. | $\frac{\sum_{p=1}^{p}(AT_{pn_i} \times Dc_{pn_i})}{Dc_{n_i}}$ |
| $Takt_{n_i}$ | 7,5 min. / piece | $\frac{H_{n_i} \times s_{n_i}}{Dc_{n_i}}$ |
| $\# RESw_{n_i}$ | 0,93 | $\frac{ATw_{n_i}}{Takt_{n_i}}$ |

*P2*, S20, Process Map 5, Module 5. *P3*, S39. *P3*, S44.

The next steps of Modules creation are repetition of the previous steps, so they are not represented. The results of them are displayed in Table 14.

Table 14. Classification of Modules

| Module i | Takti | Classification | Process Technology |
|---|---|---|---|
| Module 2 | 14,51 min /piece | Main | Assembly Line |
| Module 3 | 112,5 min /piece | Main | Assembly Line |
| Module 4 | 17,03 min /piece | Optional to Main | Supplier / Warehouse |
| Module 5 | 7,5 min /piece | Optional to Main | Supplier / Warehouse |
| Module 6 | 64,3 min /piece | Feeders to Main | Single Machine / Operation |

| | | | |
|---|---|---|---|
| Module 7 | 30 min /piece | Feeders to Main | Single Machine / Operation |
| Module 8 | 28,1 min /piece | Feeders to Feeders | Assembly Line |
| Module 9 | 112,5 min /piece | Feeders to Feeders | Assembly Line |
| Module 10 | 18 min /piece | Optional to Feeders | Single Machine / Operation |
| Module 11 | 40,9 min /piece | Feeders to Feeders | Workcell |
| Module 12 | 56,3 min /piece | Feeders to Feeders | Workcell |
| Module 13 | 23,1 min /piece | Feeders to Feeders | Single Machine / Operation |
| Module 14 | 13,2 min /piece | Feeders to Feeders | Single Machine / Operation |
| Module 15 | 47,4 min /piece | Feeders to Main | Workcell |
| Module 16 | 50 min /piece | Feeders to Main | Workcell |

*P2*, S34, S35. *P3*, S38. *P5*, S65, S67, S69.

The line balancing is a traditional problem and is addressed in the function. The operation balancing in mixed model is also addressed and a conceptual aspect of the problem is displayed below in Figure 6.

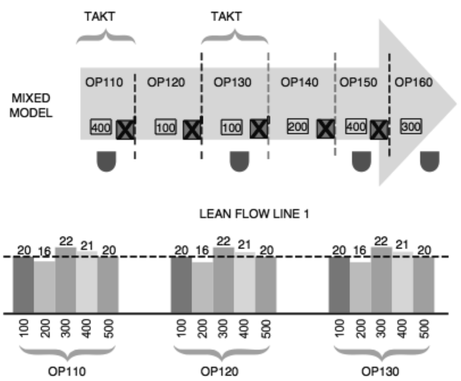


Fig. 6. *Operation Balancing in Mixed Model Production Line [5]*

*P4*, S45.

Modules with the same Takti are connected via In Process Kanban technique, see Table 17. The rest are connected via Kanban Quantities that are calculated accordingly, see Figure 7.

“Figure 7 is available upon request”

Fig. 7. *Modules Connection in Value Stream Mapping*

*P2*, S36, S37. *P5*, S51, S65, S67, S69, S72.

The Resources, Process Technology, IPKs for Operation Balancing of the Modules are displayed by Figure 8.

“Figure 8 is available upon request”

Fig. 8. *Top view of Modules and Decoupling Points including Operations and Resources*

*P3*, S42. *P4*, S47. *P4*, S50. *P5*, S51.

The ABC – XYZ Pareto Analysis results are displayed by Table 15 and 18 for Decoupling Points 1 and 2, respectively. Decoupling Points are displayed as many different storages. This is not mandatory to be implemented. The storages could be grouped into one warehouse if the situation accepts this.

The Approved sign in tables 15 and 18 means that the specific material will be handled by Kanban System. The rest will be handled by other techniques, accordingly.

Table 15. *ABC - XYZ Pareto Analysis Results per Material for Decoupling Point 1*

| Material Mmc | Classification | Kanban? |
|---|---|---|
| M13 | Y | Approved |
| M9 | Z | σ≤μ, under circumstances |
| M10 | X | Approved |
| M11 | X | Approved |
| M2 | Z | σ≤μ, under circumstances |
| M5 | Y | Approved |
| M21 | X | Approved |
| M32 | X | Approved |
| M31 | Y | Approved |
| M42 | X | Approved |
| M11 | X | Approved |
| M12 | X | Approved |
| M1 | Z | σ≤μ, under circumstances |

*P5*, S52, S54, S55.

The Production Kanban $Kal13_6$ of Material $M1_3$ that is produced by Module 6 (Assembly Line) is calculated as follows: Equation of *P5*, S56, where $T_{314\,2} = 0$, $T_{324\,1} = 0$ and m=1, c=3 και i=6. So, $Kal1_{36}$ = 10 pieces of Material $M1_3$. The Replenishment time $Ral13_6$ for Production Kanban Quantity $Kal13_6$ of Material $M1_3$ by Module 6 is calculated as follows: Equation of *P5*, S57, where $T_{314\,2} = 0$, $T_{324\,1} = 0$ and m = 1, c = 3 και I = 6. So $Ral3_6 = 620$ min. The withdrawal Kanban Quantity in Module 2 (Assembly Line), where Material $M1_3$ was delivered by Decoupling Point 1 and was produced by Module 6 is calculated as follows: Equation of *P5*, S63, where $Kwmc_i = Kwalmc_i$ with m = 1, c = 3 και i = 2, $Dc_{pi} = Dc_{42} = 7$, $Q13_{42} = 1$, $Rmc_i = Ralmc_i$ with m = 1, c = 3 and i = 6, $H_{ni} = H_{22} = 450$ min. and $Pm_{ci} = P13_6 = 1$ pcs. So, $Kwal13_6 = 9{,}64 \approx 10$ pieces of Material $M1_3$. The points, where Materials $M1_3$ are built, stored and consumed is given below: $OP2_6 \rightarrow DP_1 \rightarrow OP1_2$, *P5*, S72.

The number of Kanban cards that should be used in order to satisfy the Demand at Capacity of Material $M1_3$ is calculated: Equation of *P5*, S75, where $Ncardsm_{ci\text{->}s\text{->}I} = Ncards1_{36\text{->}1\text{->}2} = 3$, where $Kpm_{ci} = Kp1_{36} = 9.64$ and $Kwm_{ci} = Kw1_{32} = 9.09$. The number of Kanban cards for Material $M1_3$ should be 3 in order to satisfy the Demand Capacity of Material $M1_3$. Future changes in the market or sales fluctuations can be handle by adding or detracting Kanban cards. The results of logistics study are displayed by tables 16, 17 and 19.

Table 16. *Materials and logistics data in Decoupling Point 1*

| Material Mmc | Module | Decoupling Point | Withdrawal Module | Kanban Quantity | Kanban Cards |
|---|---|---|---|---|---|
| M13 | 6 | 1 | 2 | 12 | 1 |
| M9 | 4 | 1 | 2 | Min/Max | - |
| M10 | 5 | 1 | 2 | 909 | 12 |
| M11 | 4 | 1 | 3 | 29 | 10 |
| M2 | 8 | 1 | 2 | Min/Max | - |
| M5 | 8 | 1 | 2 | 7 | 4 |
| M21 | 7 | 1 | 2 | 19 | 3 |

| | | | | | |
|---|---|---|---|---|---|
| $M3_2$ | 12 | 1 | 9 | 36 | 3 |
| $M3_1$ | 14 | 1 | 2 | 564 | 3 |
| $M4_2$ | 14 | 1 | 9 | 9 | 10 |
| $M1_1$ | 15 | 1 | 2 | 10 | 1 |
| $M1_2$ | 15 | 1 | 3 | 9 | 4 |
| M1 | 16 | 1 | 2 | Min/Max | - |

*P5*, S56, S64, S66, S68, S70, S71, S74, S75.

Table 17. *Materials in IPK mode and logistics data*

| Material Mmc | Module | Decoupling Point | Withdrawal Module | Kanban Quantity | Kanban Cards |
|---|---|---|---|---|---|
| M22 | 9 | IPK | 3 | IPK | - |

*P5*, S56, S64, S66, S68, S70, S71, S74, S75.

Table 18. *ABC - XYZ Pareto Analysis Results per Material for Decoupling Point 2*

| Material Mmc | Classification | Kanban? |
|---|---|---|
| M3 | Z | σ≤μ, under circumstances |
| M6 | Y | Approved |
| M41 | Z | σ≤μ, under circumstances |
| M7 | Y | Approved |
| M4 | Z | σ≤μ, under circumstances |
| M8 | Y | Approved |

*P5*, S52, S54, S55.

Table 19. *Materials and logistics data in Decoupling Point 2*

| Material Mmc | Module | Decoupling Point | Withdrawal Module | Kanban Quantity | Kanban Cards |
|---|---|---|---|---|---|
| M3 | 10 | 2 | 8 | Min/Max | - |
| M6 | 10 | 2 | 8 | 4 | 5 |
| M41 | 11 | 2 | 8 | Min/Max | - |
| M7 | 11 | 2 | 8 | 140 | 5 |
| M4 | 13 | 2 | 8 | Min/Max | - |
| M8 | 13 | 2 | 8 | 30 | 3 |

*P5*, S56, S64, S66, S68, S70, S71, S74, S75.

The result of the Flow Customizer™ (v.1)'s function is displayed by Figure 9. The Production System is customized in accordance with demand, orders, time efficiency and resources and logistics capabilities. Any future fluctuations in demand can be simulated by the Flow Customizer™ (v.1) in order to decide to reengineer or reconfigure the production system or not.

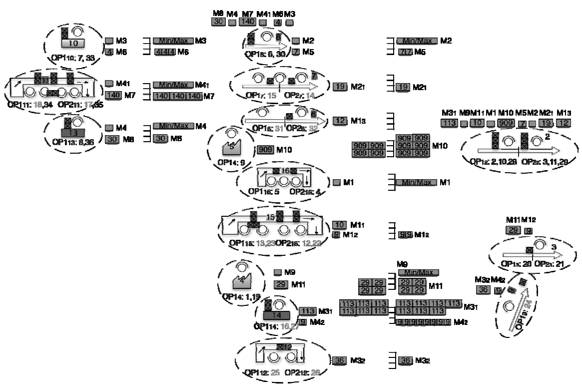

Fig. 9. *Top View of Production System including Modules, Operations, Resources, Materials and Decoupling Points 2 to 1, from left to right.*

*P7*, S85 and S88.

## 4. CONCLUSION

This work represents a system that engineers Mixed Model Continuous Flow Manufacturing. It builds Modules and connects them according to demand and orders. By this way, the system can be reconfigured namely in a simulation framework in order to assess future changes of the Production System.

Important questions for production can be answered, likewise: Should future changes of demand be followed by future changes in an already stable production system or not? Should the system remain stable in a future demand change or not? Would it be efficient to change only the production scheduling or sequencing? Which products will be build by the same Module and which will not? Is it possible for only one Module to build all the ordered products? How many Modules and how many Kanban cards will be needed to satisfy the demand in short time?

The flow is customized in order to achieve efficiency of time, resources and materials. The Modules consist of operations, resources, materials and they are balanced, following the line balancing aspects. A Modular Lean Flow Production System can be introduced by this work in order to be modeled by a future work.

Flow Customizer™ (v.1) reveals the steps of designing or engineering phase that create a production system in flow. Through these steps, challenges and problems are addressed. The steps can be classified into classical optimization problems, such as the products extraction from a Module could be transformed into a classic optimization problem. The extraction rule of this version (*P2*, S18) is a rule of thumb rather than an accurate scientific method.

Its function follows an evolutionary way of reengineering Modules and their logistics. This could lead into an automated IT tool of reengineering Production Systems.

## 5. REFERENCES

References are available upon request.

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