
8th LUMEN International Scientific Conference Rethinking Social Action.
Core Values in Practice | RSACVP 2017 | 6-9 April 2017 |
Suceava – Romania

Rethinking Social Action.

Core Values in Practice

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Lucia-Violeta MELNIC*, Gabriela IANCULESCU,
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<https://doi.org/10.18662/lumproc.rsacvp2017.44>

How to cite: Melnic, L.V., Ianculescu, G., Gurau, A.-M. (2017). A New Approach Integrated for Optimizing the Materials Flow in Production. In C. Ignatescu, A. Sandu, & T. Ciulei (eds.), *Rethinking Social Action. Core Values in Practice* (pp. 483-495). Suceava, Romania: LUMEN Proceedings
<https://doi.org/10.18662/lumproc.rsacvp2017.44>

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A New Approach Integrated for Optimizing the Materials Flow in Production

Lucia-Violeta MELNIC^{1*}, Gabriela IANCULESCU²,
Andrei-Marian GURAU³

Abstract

The production diversification and flexibility have complicated the activities in the field of production management. In these circumstances, researchers and operational managers feel, increasingly more, lack of an integrated model of synthetic industrial undertaking assigned to "black box" of it, namely the system of production. The mixt programming and allocation problem of production tasks can be dealt with in terms of optimizing the materials flow addressed as a whole in the production system. The present work presents a model for balancing the materials flow, which is based on the formal representation of the materials flow and which introduce elements of certain novelty, as well of matrix flow, the laws of evolution of the materials flow and others. The logic of materials flow formalization allows dynamic adaptive modelling and constitute the basic premise of the problem of programming and the allocation of production tasks. The emergent behavior of materials flow along with the structure of Production Planning System lead to a new logistics concept, that of Adaptive System of Production Planning and this through the development and analysis of material flow formalization elements. The main formalization elements are structured holistically and transdisciplinary as elements linking the operational management of production and operational management of the projects so that the elements of Operational Management of Production Projects.

Keywords: transdisciplinary, knowledge, production, material flow.

¹ Associate Professor Ph.D, Ovidius University Constanta, Romania, melniclucia@gmail.com.

² Lecturer Ph.D, Ovidius University Constanta, Romania, g.ianculescu.gi@gmail.com.

³ Assistant Ph.D, Ovidius University Constanta, Romania, andreigurau@yahoo.com.

<https://doi.org/10.18662/lumproc.rsacvp2017.44>

Corresponding Author: Lucia-Violeta MELNIC

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1. Introduction

It is known that today we live in a multidimensional crisis and not just into industrial one, but also economic and financial one. In fact we can say that it's a crisis created by the evolution of science and technology, also by the major transformations that mankind passes, due largely mobility and connectivity, generated by the Internet era. [1]

In this context and using the complexity culture, next to transdisciplinarity are born new visions, new proposals at microeconomic level for knowledge-based businesses as a complex adaptive system, the work product, value and surplus value have different meanings. [2]

But without transdisciplinary and creative flexible thinking, to generate original solutions, with high value and efficiency we cannot speak of understanding the present world, even at the micro level, one of its imperatives being the unity knowledge. Thus, the optimal model approach to enterprise, as complex adaptive system, of its structure and development is structural-systemic and relational-dynamic. This is a model which make integrative synthesis supplier-customer with approach structural-dynamic of procedural logistics: purchasing, production, sales/ marketing-distribution. [3]

At socioeconomic level, cost and time pressure is steadily increasing, which leads to the importance of integrated logistics management as a key factor of the globalized enterprise. Thus, the need to deliver Just-In-Time (JIT) and Just-In-Sequence (JIS) places the flow of treated material integrated into the center of the enterprise's decision-making system. Material flow simulating and modelling is a permanent updated topic in scientific literature and specialized practice.

In the present work, we define the notion of materials flow in the production subsystem on the basis of an individual fabrication process. [4] The notion of material flow is treated in literature, on the one hand, integrated, through a systemic approach of enterprise, and on the other hand, sequential at subsystems enterprise levels, namely: supply, sales-distribution. [5] The material flow is a distinct entity that turns in value based on a manufacturing process from raw material to finished product [4]. In this transformation, supported by the material flow, as a distinct entity, from raw material to finished product the value added is the difference between the cost of raw materials and the cost of the finished product. The material flow is analyzed as a distinct entity with emergent behavior and will be achieved in a formalized frame characterized by elements, specific economic dynamics that have the following characteristics in common [6]:

- simplicity, as working hypothesis - we assume that the simplest solution is the best, considering the time as operational variable;

- change, as the base and incremental process -changing requirements must be regarded as a process of adaptation issues and implemented in steps;
- quick feedback, as a measure of adaptation - the time between one processing and its feedback need to be as short as possible;
- Value added, as a parameter to accept - the results must match economic requirements.

The emergent behavior of materials flow along with the structure of Production Planning System (PPS) lead to a new logistics concept, that of Adaptive System of Production Planning (ASPP) and this through the development and analysis of material flow formalization elements [4]. The main formalization elements are structured holistically as elements linking the operational management of production and operational management of the projects so that the elements of Operational Management of Production Projects (OMPP). OMPP models are based on the following elements: identification and prioritizing of project activities; identification of logistics manufacturing material flow; identifying and allocating resources for the project; quantification of material flow at economic lot level using the production project resources through durations, loads and intensities.

Thus, the organizational knowledge of material flow management came from transformed information's by those who have the capacity to act effectively, through assimilation and integration understanding followed by operating within a given context. According to OECD statements - Organization for Economic Co-operation and Development "...The organizations need a number of new indicators to evaluate stocks and knowledge flows, related to the dissemination of information technologies, including manufacturing and service branches, the benefit obtained as a result of investments in knowledge, creation and dissemination network operation knowledge, innovation systems through knowledge, human capital development and capacity ...".[7]

In this context, it consider the material flow as a resource center. According to Booz Allen & Hamilton Model, it's "a contact center for collecting, structuring and disseminating information" so a specialized center in "knowledge management" responsible for material flow managing at the mix logistics supply-production-sales level (identification, labelling and indexing of the knowledge sources, maintaining and supporting a resource registry that's generate material flow etc.). [8]

The flexibility degree of the Adaptive System of Production Planning (ASPP) can be improved in organization by the existence of a "knowledge management" center, that will manage integrated the material flow.

2. Theoretical Background

All these elements arising out of the production project analysis, leading to the possibility of problem formalization of optimizing the materials flow, as unique and measurable objective of project production, quantified individual by Transformation Diagram of Materials Flow (STFM) which is represented by elements specific to ASPP, namely: the Flow Processing Units (UFP); Flow Units in Standby (UFA). This is unique and is carried out for each processed item, in accordance with the manufacturing process stated in terms of optimum technical. [9] A fundamental element in the materials flow formalization, consisting of two or more technological schemes of the materials flow is the Technological Network of Materials Flow (RTFM).

UFP quantification, at manufacturing lot level is achieved through technological operation code, operation time, and the resource code and resource intensity (**figure 1**). UFP represents formally a manufacturing activity that consumes time and resource to be achieved. *UFP duration* [time units] is given by the length of the technological operation from technological process of item realization, at fabrication lot level. *Intensity* [%] is given by the percentage of the resource's calendar allocated to technological operation, within the technological process of lot production. The code of the processing flow unit is represented by UFP_{ik} , where i ($i = \overline{1, n}$) is number of the item entered in processing and k ($k = \overline{1, p}$) is the number of technological operation of the technological scheme of item i (*STFM*). The technological operation time is according STFM, represented by the unit time t_{ik} , of parts lot processing, at every operation k . Technological operation code is represented by COD_{iq} , where q ($q = \overline{1, s}$) is the number of technological operation of the same type within *RTFM*. The resource code allocated to technological operation is represented by: R_j , where j ($j = \overline{1, m}$) represents the number resource from SPP.

UFA quantification is achieved through technological operation time k from the technological process, at manufacturing lot level. UFA represents formally a standby type activity that consumes time to be accomplished and that is graphic represented as link type *S-I* between the *UFP*. The *UFA* duration has the minimum waiting time meaning what separates two *UFP* within the technological process and depends on the type of production organization (mixed, parallel, successively). Standby flow unit code is represented by: $UFA_i^{k, k+1}$ (**figure 1**).

STFM is formed by n stream processing units (*UFP*), represented by blocks (nodes) and $n-1$ standby flow units (*UFA*) represented by arrows, as links between the *UFP* (figure 2).

Balancing the materials flow at *RTFM* level, through the adaptive work program (*PAL*) in manufacturing, leading to the existence of an adaptive system of production planning (*SAPP*) and thus the operational management of production will have a remarkable ability by adapt to continuous changes arising from a complex and dynamic environment [10].

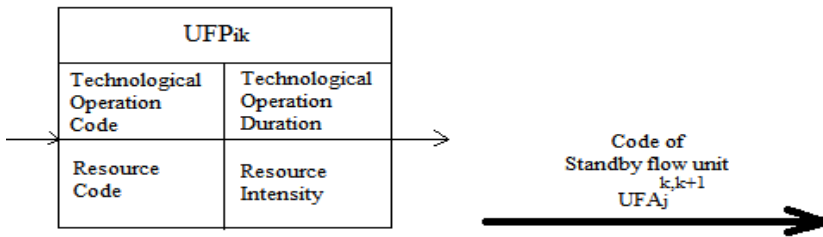


Figure 1. Flow Processing Units

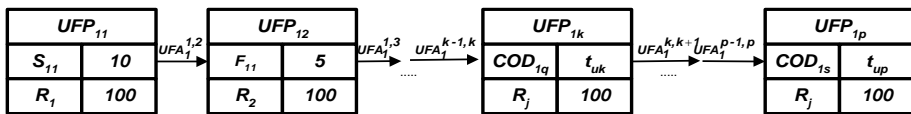


Figure 2. Transformation Diagram of Materials Flow

At the level of each project, *RTFM* contains *STFM* for each item that should be executed and two fictitious flow units (*UFF*) (figure. 3):

- Fictitious flow unit of input (*S*) – formally represents a fictional type activity (is not consume any time or resource to be achieved).
- Fictitious flow unit of output (*F*) - formally represents a fictional type activity.

Optimizing the materials flow at *RTFM* level leads to creation of an *ASPP*, through which it will be able to anticipate change and adapt to a dynamic environment in a planned and integrated manner. For a detailed description and solving the optimization model of the materials flow (*OFM*), with the objective of balancing the materials flow at *RTFM* level, must be presented some concepts related to the formalization of the materials flow. The characteristics of materials flow balancing *RTFM*, as formal representation of *ASPP*, will lead, by treatment with specific algorithms, at adaptive work programs (*PAL*), of which duration follow to be optimized.

2.1 Mathematical model of material flow optimization

For achieve this model in dynamic environment of production systems, takes the first fundamental mathematical notions that define the elements of formalization. It's define $P_{ik} \in R^+$ the duration of the flow processing units UFP_{ik} from RTFM.

It's define $S_{ik} \in R^+$ date, earliest start programmed for each flow processing unit UFP_{ik} from RTFM. For realizing the OFM model and, at the same time, as its own definition RTFM, it is accepted that the duration of the fictitious flow unit (UFF) is 0 and the PAL time beginning is considered to be zero moment, relations presented mathematically as follows:

$$P_{i,0} = P_{i,p+1} = 0; S_{i,0} = 0 \tag{1}$$

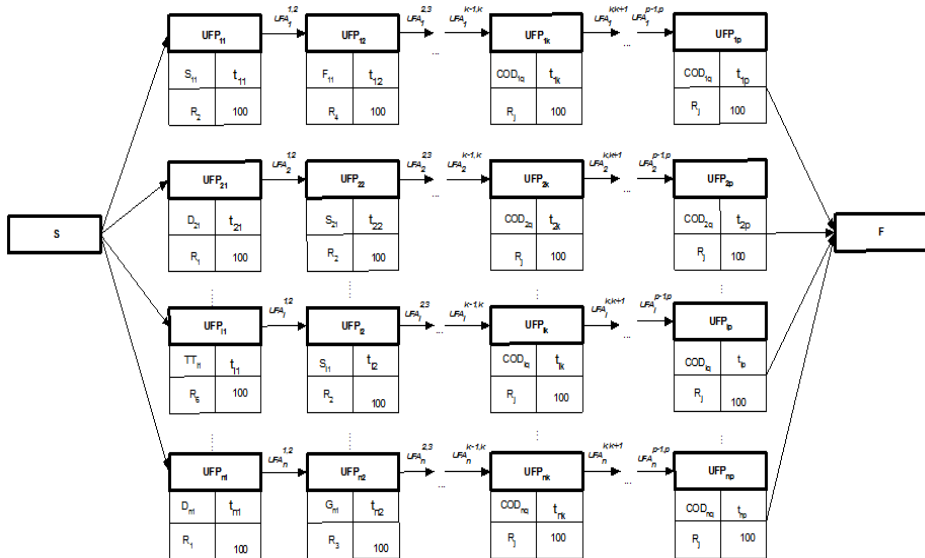


Figure 3. Technological network of materials flow

It is assumed that is a maximum time of PAL predefined by relation:

$$d^- \in R^+ \text{ With condition } S_{i,p+1} \leq d^- \tag{2}$$

To be able to shape the RFM, it will be considered a graphical representation which includes the following elements:

- Nodes UFP_{ik} as the strings labelled (i, k) with $i = \overline{1, n}$ and $k = \overline{1, p}$, representing all the processing flow units, characterized by duration (P_{ik}) and load ($r_j, j = \overline{1, m}$).

- Arcs $\mathbf{UFA}_i^{k-1,k}$ between nodes ($UFP_{i,k-1}$ UFP_{ik}), representing all standby flow units characterized by duration symbolized $D_{k-1,k}$ for each i item and sequence of operations ($k-1$, k).

$D_{k-1,k}$ duration is equal to the gap between successive UFP at i item level in processing with condition:

$$D_{k-1,k}^{\min} \leq S_{ik} - S_{i,k-1} \leq P_{i,k-1} \quad (3)$$

it follows a condition of time-log min (minimum waiting time) in which the UFA duration to be the smaller.

The heuristic method, applied in establishing balance of load-capacities, will schedule successively UFP_{ik} in RTFM with finite capacity variable so that the total duration of the production project to be minimal. This objective is materialized in an optimization function as "min" type, applied to duration that characterizes $UFA_i^{k-1,k}$, and achieved using *heuristic algorithm of frame delay AEL*.

The problem that arises is that of determining the optimal PAL duration in terms of resources with finite capacity variable (extensible resource), using heuristic methods. The number of resources with finite capacity variable is set, in function of cost and time, between a maximum number, equal to the total UFP number, and a minimum equal to the UFP that using different production resources.

2.2. Evolution laws of materials flow.

The problem of optimizing the materials flow (OFM) is a mixed issue of programming and allocation of resources in terms of a finite variable capacities. This problem will be solved first in terms of a finite capacity, after which, with the help of a optimization model of the resources number, will be solved the OFM problem in terms of variable capacity. [11]

The CMD matrix flow (MFD), is obtained from the RTFM treatment in relation to a time scale which has the origin in t_0 and goes to the future.

The CMT matrix flow (MFT), is obtained from the RTFM treatment in relation to a time scale which has the origin in t_f and goes to the past.

Thus, we define four moments that delineates as time an UFP_{ik} : two CMD moments (DS_{ik} - *earliest possible time to start*; $DF_{ik} = DS_{ik} + P_{ik}$ - *earliest possible time to finish*) and two CMT moments (TS_{ik} - *the later start time*; $TF_{ik} = TS_{ik} + P_{ik}$ - *the later finish time*) (figure 4).

The fluctuation interval (IF_{ik}) (time margin) of each UFP_{ik} is defined as the difference between the CMT starting date and the CMD starting date. In RTFM case (figure 3) the critical path is not a simple sequence of critical UFP_{ik} , that succeed after a strict rule set according to the type of end-start

link between the two *UFF* (*S* and *F*), but an assembly of critical UFF_{ik} , that it can process in parallel to.

The critical UFF_{ik} will have S_{ik} moments at the earliest start time determined in accordance with schedule of production in terms of infinite capacity. [12]

DS_{ik} and TS_{ik} moments are the moments that will define the range of fluctuation – time margin (IF_{ik}) of each UFF_{ik} , so:

$$IF_{ik} = TS_{ik} - DS_{ik} \quad (8)$$

Problem of UFF_{ik} , scheduling, at RTFM level, in terms of infinite capacity has a feature that makes it different from conventional programming issues. This feature starts from the fact that UFF_{ik} comply with a well-established law based on *technological process* of product development represented formally by STFM. As a result the *matrix flow* represents the key element in analyzing and processing data from STFM, with the purpose of OFM model solving. The matrix flow is represented by levels of flow characterized by the allocation degree, $\pi_{jq} \in N, j = \overline{1, m}, q = \overline{1, s}$, for each UFF_{ik} from RTFM. Conventional it names the *flow level balanced*, the level which has level allocation equal to 1. The system data, at flow matrix level, led by analyzing and processing, to the information of time scheduling and allocating the resources required for each UFF_{ik} , in compliance with the *Basic Law of Material Flow (LFFM)* which is set out as follows:

The material flow, as distinct entity with emergent behavior, is transformed, from raw material to finished product, based on a univocal evolving technological process.

Consequence: the basic law of the materials flow meet to the manufacturing process of the product.

Because the manufacturing is simultaneous, in different time periods, levels of MFI will be overloaded ($\pi_{jq} > 1$), and to determine the work programmer, the materials flow must comply with the *Law of Continuity (LCFM)* expressed as follows:

Material flow is continuously adaptive, throughout the total process, if and only if the allocation degree of all levels (N_j) from matrix flow is equal to 1, respectively $\pi_{jq} = 1, (\forall) j = \overline{1, m}; q = \overline{1, s}$.

If at MFI level, for a flow level, we have an allocation degree $0 \leq \pi_{jq} < 1, j = \overline{1, m}; q = \overline{1, s}$, it means that there are production resources who work with lower intensities of 100%, fact that contradicts the hypothesis made originally on the use of resources. The work programmer has achieved a balanced adaptive materials flow but not optimized, it realized by optimizing the number of levels from the integrated matrix flow.

The work programmer, is represented by a matrix flow with j flow levels where $\pi_{jq} = 1, (\forall)j = \overline{1, m}; q = \overline{1, s}$ the allocation degree of flow level is. This operation of obtaining the materials flow continuity, will be achieved using a heuristic algorithm of frame delay (AEL) which aims at keeping the continuity law of material flow at matrix flow level, so getting an allocation degree of flow levels equal to 1. *The work programmer* (PL), in terms of finite fixed capacity, is an integrated matrix flow (MFI), which complies with the basic law of materials flow (LFFM) and the continuity law of material flow (LCFM).

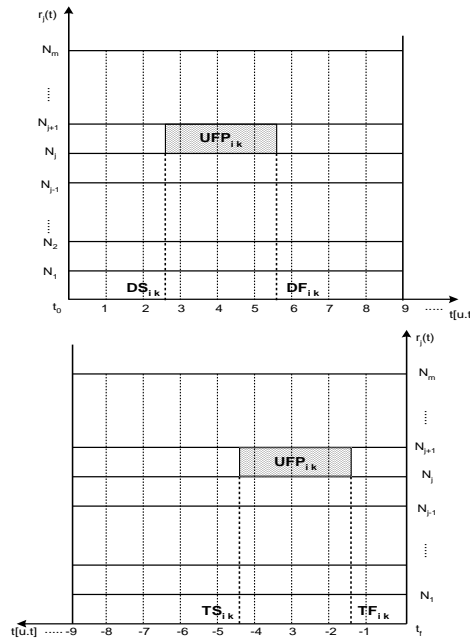


Figure 4 Flow Processing Units four moments

2.3. Presentation of frame delay heuristic algorithm elements - AEL

It should be noted that the elements and frame delay process will be defined and analyzed on a time scale CMD . The main elements which AEL is carried out are:

- flow unit in processing UFP_{ik} , characterized by duration P_{ik} , that is constant during the entire production project, an earliest possible time to start DS_{ik} , an earliest time to finish $DT_{ik} = DS_{ik} + P_{ik}$ and load r_j where $i = \overline{1, n}; k = \overline{1, p}; j = \overline{1, m}$;

- Standby unit flow $UFA_i^{k-1,k}$, characterized only by duration, $D_i^{k-1,k}$, that is variable during the production project but having a minimum constant value, determined by type of organization.
- integrated matrix flow (MFI), that contains a number of $N_j, j=\overline{1,m}$, flow levels and which, in terms of a finite capacity, is constant throughout the entire production project;
- Degree allocation of flow level $\pi_{jq} \geq 1$, where $q (q=\overline{1,s})$ is the number of technological operation of the same type at the RTFM level.
- Flow unit delay (UFL_{ik}) is the flow processing unit (UFP_{ik}) that lead to variation of the standby flow unit duration ($D_i^{k-1,k}$) as a result of the frame delay process.

Frame delay process represents the modality in which is realized the delay operation of UFP_{ik}, at one moment, when the allocation degree is larger than 1, so it is not respected the Continuity Law of Materials Flow (LCFM) (figure 5).

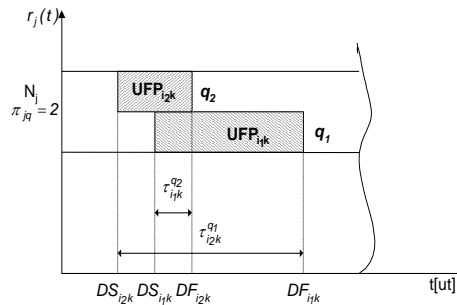


Figure 5. Allocation degree $\pi_{jq} = 2$

AEL include the applied delay processes, in ascending order, to all flow levels of MFI in terms of fixed finite capacity, and aims to achieve the programmer of work in the workshop (*PL*).

Heuristic Algorithm of Frame Delay (AEL)

Step 1: It settles on MFI level, in conditions of fixed finite capacity, the flow levels number N_j and the allocation degree of each flow level $\pi_{jq}, (\forall) j=\overline{1,m}$ and $q = \overline{1,s}$.

- If $\pi_{jq} = 1, (\forall) j=\overline{1,m}$ then MFI comply with LFFM and LCFM, which will lead to her assimilation with PL, then STOP.
- If $(\exists) N_j, j=\overline{1,m}$, for which $\pi_{jq} > 1$, it will move to Step 2.

Step 2: It will be applied at the flow level N_j , of MFI, the process such:

- If $\pi_{jq} = 2$, then it will realize a single delay operation; the flow unit delay $UFL_{ik} : DS_{ik}^L = DS_{ik} + \tau_{ik}^q$ and $DT_{ik}^L = DS_{ik}^L + P_{ik}$; τ_{ik}^q is a random variable and $\tau_{ik}^q = \min_t(\tau_{i_1k}^{q_1}, \tau_{i_2k}^{q_2})$. If it obtain $\pi_{jq} = 1, (\forall)j = \overline{1, m}$, so it complies with LCFM, it will move to Step 3.
- If $\pi_{jq} = 3$, then there will be more delay operations; the flow unit delay $UFL_{ik} : DS_{ik}^L = DS_{ik} + \tau_{ik}^q$ and $DT_{ik}^L = DS_{ik}^L + P_{ik}$; τ_{ik}^q is a random variable and $\tau_{ik}^q = \min_t(\tau_{i_a k}^{q_b})$ where $a = \overline{1, n}$ and $b = \overline{1, s}$, and the intervals number is $2 \cdot C_q^2$. If it obtain $\pi_{jq} = 1, (\forall)j = \overline{1, m}$ it will move to Step 3.
- If $\pi_{jq} > 3$, then it will enter into MFI a new flow level N_{j+1}^j , which formalizes technological the flow level N_j , and the frame delay procedure will continue as in step 2. If it obtain $\pi_{jq} = 1, (\forall)j = \overline{1, m}$ it will move to Step 3.

Step 3: It will perform the drag operations in order to respect the *previous character* between the UFP_{ik} , according to RTFM, as a fundamental element of technological formalization of the ongoing project production. After checking the LFFM and LCFM, at the flow level N_j , it will move to Step 4.

Step 4: It will repeat the procedure from Step 2 and Step 3 at all MFI levels.

The problem of job-shop scheduling, has undergone a huge number of works whose synthesis can be seen in [13] in the simple form. In this works has not been taken into account the fact that the materials flow is a distinct entity that respects a LFFM and that, to be fluidic in real time at the workshop level, must comply with and the LCFM based on AEL, notions introduced in the present work.

3. Argument of the paper

The OFM model, in order to determine the PAL, in which the material flow is optimized represents a solution for the existence within the enterprise of SAPP, so a convenient solution to solving nonlinear stochastic system and by developing the OFM metaheuristics. [9] The decision of PAL application is fundamental in SAPP, this leading to a production planning in real time and thus production schedule becomes an integral part of planning.

4. Arguments to support the thesis

For solving job-shop production scheduling, exists in the literature two approaches considered to be "in real time" but developed as algorithm in static or dynamic context. It was concluded that heuristics algorithms, considered to be the closest to real situations, has on base rules of priority developed in the production scheduling and which solves the problem in static context [14]. Thus, real-time approach, in *static context*, based on static problem solving consists in controlling, compliance with the proposed sequences and the start data provided, and new production tasks, in manufacturing plan or changes in the operation of the resources, lead to the creation of a new static problems and so the algorithm is very laborious and long. The greatest difficulty of this approach is to set the start date of a work under the conditions of new data requirements (constraints) [15]. In *dynamic context*, the assemble of production loads supposedly is not known in advance and production schedule horizon is infinite. The dynamic aspect of the problem comes from the availability of resources to carry out the production loads and management of "waiting in front of resources" cases, which are validated using simulations of carrying out works in the workshop.

5. Arguments to argue the thesis

The specialized scientific literature, in large part, treats the flow of sequential material at the logistics sub-sites level. Studies have shown that optimizing sequential materials flow does not lead to minimizing cost and time of making a product as well as a service. An integrated treatment of losses in the value flow can be achieved by material flow optimizing at the adaptive production planning system.

6. Conclusions

The original proposal for the determination of PAL as a result of resolving OFM, makes subject to new approaches and specific adaptive dynamics approach of SPP through the existence within the organization of SAPP. Adaptive System of Production Planning (SAPP) formalized with RTFM, has as unique purpose, obtaining of PAL using the OFM model. SAPP, in the context of mix logistics, develop an adaptive dynamic of materials flow balance. This notion is an interaction between the equilibrium dynamics of materials flow and evolutionary adaptation of SAPP to constraints from internally or externally of company.

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