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OPTIMIZATION OF BAR CUTTING PROCESS

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Abstract: *Among the authors' interests we enumerate integrated Kanban processes, fields in which the authors published a few papers. An important technical-economic issue in manufacturing heat-insulation materials is the optimization of the cutting process of expensive bars using numerical-controlled cutting machines, in view of reducing the losses of bars ends. Apparently simply as phenomenon, the optimization of bars' precise cutting process, integrated in Kanban processes, is complex but increases the efficiency of the cutting process by reducing the material losses. The paper presents the diagram of organizing the cutting department, of optimizing the process and algorithm of department operation.*

Key words: *cutting process, optimization*

1. OBJECT OF THE PAPER

Following up the papers [1, 2, 3, 7,] elaborated in the last four years by the authors of the present paper, the goal is to develop the physical and functional model of bars cutting department. At the basis of these developments lies paper [6]. The main objective of the paper is the elaboration of the optimization model for bars cutting process, integrated in a Kanban process.

2. CURRENT STATE OF THE PROBLEM

The authors of papers [1, 2, 6, 7] analyzed the current manufacturing process (reference year 2003) of heat-insulation carpentry in a Romanian factory and forwarded solutions for factory reorganization on basis of integrated Kanban processes; these solutions have been applied since 2005 and the forward-looking models developed in papers [3, 4, 5] proved to be viable ever since 2006.

The problem dealt with in this paper has been approached, worked out and applied in real industrial environment since 2005.

The paper aims at optimizing the cutting process of PVC bars in manufacturing heat-insulation carpentry.

3. COMPOSING THE CUTTING STATION

Bars cutting represent the first operation in the flow of material processing, being located on the flow input (upstream)

Taking into account the fact that the cutting process is conducted on three different types of materials and bars profiles - PVC, OL and Al, on three different machines, they will form the *cutting station*, placed on *input* (upstream) in the manufacturing flow. The number of cutting machines and their automation degree results from Fig. 1. Consequently, the cutting station will be made up of three independent work sites (PVC, OL, Al), which work in parallel, each being composed of: PLPVC (2 machines), PLOL (2 machines) and PLAl (1 machine).

The material couplings of the cutting station are: on the input - with the materials warehouse, and on the output - with the following work sites (insertion, tracing, assembling)

The structure of the material processing flow through integrated Kanban processes will be ordered in parallel – series (mixed type), according to the material storage model [7, 1, 2] where Stl_i is the cutting station; ($PL_{(j-1)}$, PL_j, $PL_{(j+1)}$) are the work sites for cutting bars made of PVC, OL and Al, each including the number of machines previously stated; $PL_{(i-1)}$ does not exist; DzM exists as materials warehouse for the safety stock (SS) in line, which substitutes $PL_{(j-1)}$; mobile $ST_{i,i}$ and $ST_{i,d}$ exist for the stock on flow (SF); P_i = PRa and P_d = PRe of StD_k exist as well. Consequently, the graphical model of particularized integrated KANBAN process will be the one in [7, 1, 2], and the diagram of ordering and organizing the cutting technological flow is presented in Fig. 1.

In Fig. 1, the following notations were used: MD – cutting machine; PVC, OL, Al - PVC, steel, aluminum, AL - supply; PL(I+S) - insertion-welding work site -; PLTs - tracing work site, R - fixed creels; CRM - mobile trolley creel; CB - bar end; Pi,d - loading - unloading site; TpRt - return conveyance.

The cutting station is provided with three distinct categories of cutting machines: two for PVC, two for steel and one for aluminum.

The materials warehouse is equipped with one DzM for all types of materials and with two fixed creels, one for each optimized bar end (RCB) made of PVC and another for Al; three distinct material flows emerge from DzM - one for PVC, the second for steel and the third for aluminum. The aluminum processing flow is independent, and the other two are dependent and concurrent on the same welding and insertion work site.

The functions Lv / Tp and AL in the diagram presented in Fig. 1 are assured by mobile storing devices on flow ST - $(Lv / Tp, AL)_k$, materialized through $SbTp_k$, k = PVC, OL, Al, composed of $SbTp_k$ = {CRM_{ki}; $k = 1 \triangleq$ PVC, $= 2 \triangleq$ OL, $= 3 \triangleq$ Al; $i = 1 \triangleq$ loading, delivery, conveyance, supply, $i = 2 \triangleq$ r recycling the bar ends in/from fixed creels for bar ends made of PVC and Al, *i*

= 3 ^ mobile trolley creel on the StD output for (Lv / Tp, AL)$_k$ of following PL}, to assure operation conditions in Kanban processes. The mobile storing devices on flow, noted with CRM_{ki} may occur in various constructions, the ones adopted having the trajectory guided on the floor (materialized) and trajectory that is not guided on the floor (with wheels)

Since the frequency of Al processing is very low as related to OL processing, and this has a smaller duration than PVC processing, there was adopted the solution of using a common SbTp for materials made of Al and OL, resulting the diagram of DzM and StD.

The loading/unloading posts (PRa/PRe) do not occur explicitly but composed of SbTp/Lv/AL.

4. OPTIMIZING THE BARS CUTTING PROCESS

The bars cutting process, from systemic point of view, must be regarded at global level, as a whole, and evaluated through the totality of directly and indirectly productive, material and information activities that constitute the whole cutting process. Consequently, the optimization of bars cutting has to be conducted on the whole cutting process not on isolated stages.

The aim of optimizing the cutting process is to minimize the losses from each k bar (k = PVC, OL, Al), as well as from each bar with similar profile, taken separately. The notations used for this goal are: Ln - nominal length of the cut bar, necessary in subsequent material processing, variable with the product Rk; L_{bi} - length of initial, complete bar of 6 m; L_{CB} - length of the bar end left after the first cutting, less than 6 m, recycled the first time in RCB_k; L'_{CB} - length of bar end left after the second and subsequent cutting, less than 6 m, recycled the second and subsequent time in RCB_k; x - current bar end. The following cases may occur during processing: $x = L_{bi} - \Sigma Ln$, $x = L_{CB} - Ln$, $x = L'_{CB} - Ln$; p_a - admitted loss of bar end, imposed through the management decision.

The diagram of optimizing the bars cutting process is presented in Fig. 2 where: C*ij* is the current *ij* component of the manufacturing system; PS*ij* - software product necessary in the optimization process; *ECN* - numerical control equipment of MDk; CP - comparing element in the optimization process; AF - system display; RaM - material ramification.

At the basis of optimization process lie the lists with stock of complete bars L_{bi} = 6 m in *PS5 – Y5*, existent in DzM = *C*12 – *Y*12, updated through ApM = i_{FM} – *x*121and *x*52 and re-updated through *x*51 and the stock of bars ends L_{CB} < 6 m existent in RCBk – C13 received from MDk – C15 through CRM2 – C19, updated through *x*133 and re-updated thorough *x*61 and *x*62 on PS6 – *Y*6. These lists are founded on PS3 and PS4 basis, resulted from PROIECT – C1 – *Y*11*P*.

The optimization process has two components: automated and material component.

Computed component: The computed component contributes to the following decisions:

1) If $L_{CB} < Ln$ then PS9 emits the signal *Y*91 = *x*62 on *PS*6 and this is retained on the list;

2) If $L_{CB} = Ln$ then $x = p_a = 0$ and PS9 emits the signal *Y*92 = *x*132 on C13 = RCB_k and the bar is extracted from RCB_k and is transferred to the container CRM1 = C14, *Y*13 = *X*142;

3) If $L_{CB} > Ln$ then $x > p_a$ resulting two other decisions:

a) $L_{CB} = Ln + x$ and $x \le p_a \ne 0$, then PS10 emits the signal *Y*101 = *x*131 on C13 = RCBk and the bar is extracted from RCBk and it is transferred to container CRM1 = C14, *Y*13 = *X*142;

b) $L_{CB} = Ln + x$, $x = L'_{CB > pa}$, then PS10 emits the signal *Y*101 = *x*131 on C13 = RCBk and the bar is extracted from RCBk and is transferred to container CRM1 = C14, *Y*13 = *X*142;

4) If $L_{bi} \ge Ln$ then $x \ge p_{a,}$ resulting two other decisions:

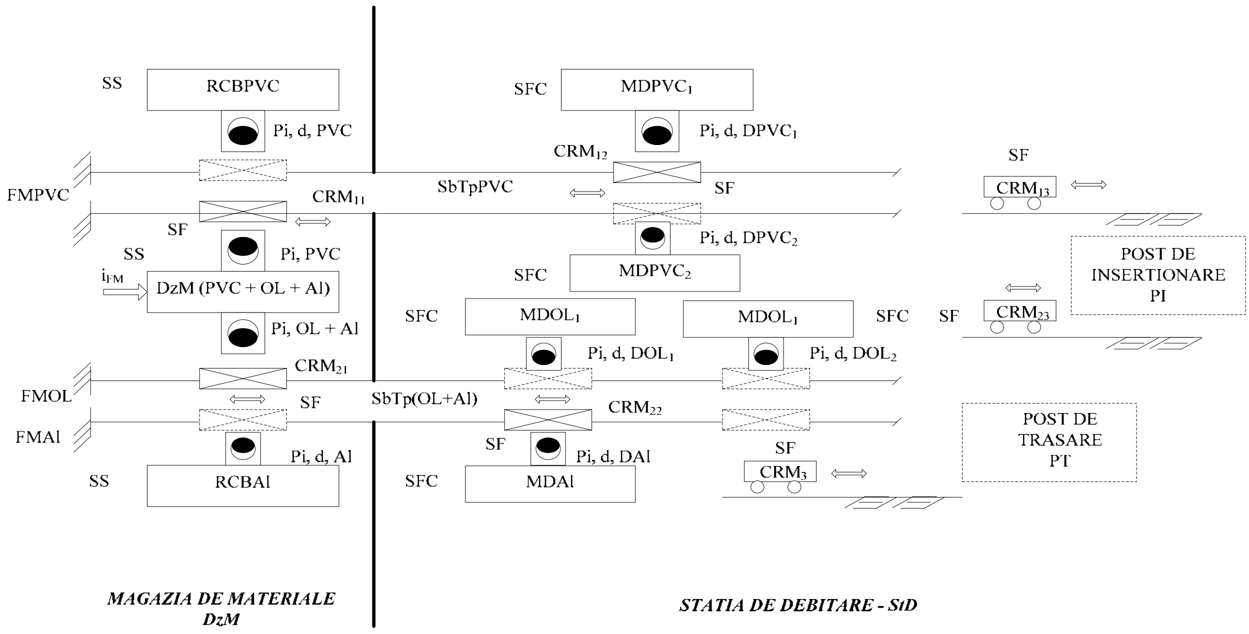

Fig. 1. Diagram of ordering and organizing the cutting technological flow.

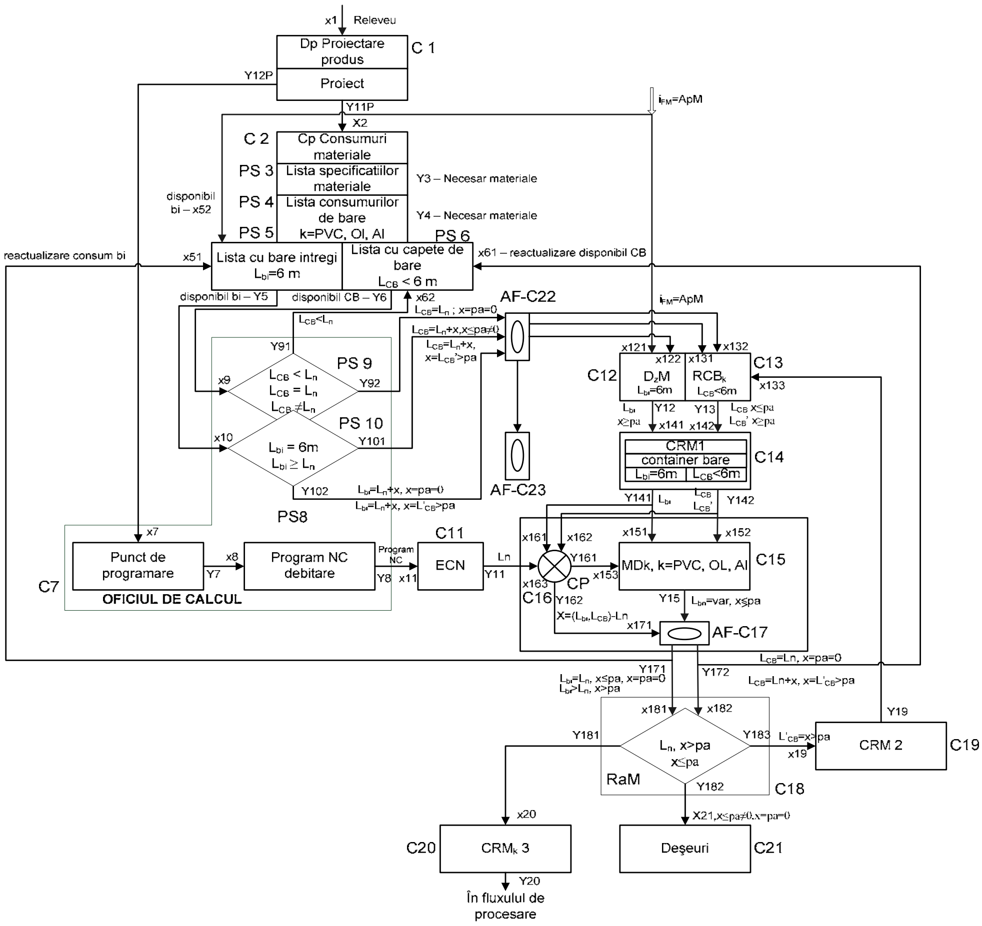

Fig. 2. The diagram of optimizing the bar cutting process.

a) $L_{bi} = Ln$ or $\Sigma\, Ln_i$ when $x = p_a = 0$, then PS10 emits the signal $Y102 = x122$ on C12 = DzM and the bar is extracted from DzM and is transferred to container CRM1 = C14, $Y12 = X141$;

b) $L_{bi} = Ln + x$ when $x = L'_{CB} > p_a$, then PS10 emits the signal $Y102 = x122$ on C12 = DzM and the bar is extracted from DzM and is transferred to container CRM1 = C14, $Y12 = X141$;

The company's policy imposes L'_{CB} = variable according to stock volume on CB in RCB, $L'_{CB} \in$ (L'_{CB} = 300 mm, L'_{CB} = 350 mm, L'_{CB} = 400 mm).

The *stage of elaborating the CNC cutting program* belongs to the automated component and consists of the following automated-related activities:

1) On the basis of designing drawings of the project C1 – $Y12$, at the programming point C7 – $X7$ there is developed the NC cutting program PS8 – $x8 = Y7$;

2) The NC cutting program is transmitted ECN – C11 – $x11 = Y8$ which transmits the information $Ln = Y11$ in CP – C16, with the role of emitting the message $x153 = Y161$ to MDk – C15 and of fulfilling the comparison $x = (L_{bi}, L_{CB}) - Ln = Y162$ in AF – C17, useful OpU for marking the left bar end, through labeling.

Material component: The material component contributes to the following decisions and activities that are directly and indirectly productive:

1) The complete bars (bi) are to be found in containers arranged on types of materials (PVC, OL or Al) and codified on profiles, in DzM. The bar ends (CB) are arranged in various compartments of RCBk, on types of materials and profiles and can be identified through:

- *department label* specific to shelf expressing the material's code (PVC, OL, Al) and profile; the department label is fixed;

- *bar label,* expressing the material's code, profile and length of bar end (L_{CB}); this is conveyed by each bar on the trajectory of its movement in the processing flow, it is of "barcode" type, it is read with an opto – electronic device (scanner), in both C13 – RCBk and C18 – RaM. The bar label changes together with the change of the bar length, (L_{CB}, L'_{CB}) = var after cutting in C15 = MDk; the bar level turns into C18 – RaM.

2) By displaying C22 – AF, the human operator (OpU) receives the identification and selection messages of a number of bars of similar type. Through message $x122$, OpU selects and extracts from DzM a number of complete bars – $Y12$ and transfer them to CRM1 – $x141$; through messages $x131$ and $x132$, OpU selects and extracts from RCBk the required number of bar ends of each type – $Y13$ and transfer them to CRM1 – $x142$.

3) CRM1 is transferred/received from MDk, $Y141$, $Y142$ / $x151$, $x152$.

4) According to messages displayed in C23 – AF, OpU supply MDk with the required bar. MDk supply is done manually after identification and selection, by reading the bar label with the optical device, which emits signals in C16 = CP, ($x161$ U $x162$).

5) *MDk* fulfills the material processing through the cutting process by the intermediary of C11 – ECN, according to program *Y*8 & *Y*11 & (*Y*161 = *x*153), delivering on output *Y*15 – bars with nominal length L_{bn} = var, using signals *x*153 = *Y*161.

6) In the display C17 – AF, OpU reads visually *Y*15 = L_{bn} = var = *Y*171 and *Y*162 = ($x = (L_{bi,} L_{CB}) – Ln$) = *Y*172 and through the optic device it emits: signals *Y*171 = *x*51 expressing the integral consumption of the complete bar $L_{bi} = \sum Ln$, $x \le p_{a,}$ or on the partial one *X*61, $L_{bi} > \sum Ln$, $x = L'_{CB} > p_a$ for updating PS5; the signal *Y*172 = *x*61 expressing the integral consumption of the bar end $L_{CB} = Ln$, $x \le p_a$ or partial $x = L'_{CB} > p_a$ for re-updating *PS*6.

7) In C18 = RaM, OpU handles bars with Ln in CRMk3 = C20 which will be sent on the upstream material flow *Y*20; *x*20 = *Y*181 = *x*181 = *Y*171; the tailings $x \le p_a$ to wastes C21 – *x*21 = *Y*182 and newly resulted bar ends $L'_{CB} = x > p_a$ will be handles in C19 = CRM2 for recycling in RCBk – C13, that is *x*133 = *Y*19 = *Y*183 = *x*182 = *Y*172.

All he decisions and activities previously mentioned are expressed through the following *operation algorithm* of the cutting station with *optimized processing*, run by a *numerical control-based program*.

Initially fulfilled conditions: (Y11P, Y12P) = 1, (Y3, Y4, Y5, Y6) = 1, (Y8, Y11 = Ln) = 1, x121 = i_{FM} = 1.

Operation algorithm

STEP 1 = S1 IF *Y6* THEN *x9* ($L_{CB} \neq Ln$)

S2 IF *Y91* ($L_{CB} < Ln$) THEN (*x9* & GO ON *S3*)

S3 IF *Y92* ($L_{CB} = Ln$, $x = p_a = 0$) THEN (x132 & SELECT LABEL KTL_{CB}) ELSE GO ON S5 where: K – material (PVC, OL, Al); T – type (profile); L_{CB} - length (lenght of bar end - L_{CB})

S4 IF SELECT LABEL KTL_{CB} THEN EXTRACT FROM RCBk AND TRANSFER CRM1 – Y13

S5 IF Y101 ($L_{CB} = Ln + x$, $x = p_a = 0$; $L_{CB} = Ln + x$, $x = L'_{CB} > p_a$) THEN (*x131* & SELECT LABEL KTL_{CB}) ELSE GO ON S7

S6 IF SELECT LABEL KTL_{CB} REPEAT S4

S7 IF Y5 THEN *x10* (L_{bi} = 6 ml)

S8 IF Y102 ($L_{bi} \ge Ln$; $L_{bi} = \Sigma\ Ln$, $x = p_a = 0$; $L_{bi} = Ln + x$, $x = L_{CB} > p_a$) THEN (*x122* & SELECT LABEL KTL_{CB})

S9 IF SELECT LABEL KTL_{bi} THEN EXTRACT FROM DzM AND TRANSFER CRM1 – *Y12*

S10 REPEAT S1 … S9 AS FAR AS TO EXHAUST (PS6 & PS5)

S11 IF (*Y13* & *Y12*) THEN (*Y141* & *Y142*) – CRM1 GO TO MDk (*x151* & *x152*)

S12 IF (*x151* &*x152*) THEN IDENTIFY LABEL (KTL_{CB} OR KTL_{bi}) FROM CRM1 AND TO FEED MDk (*x161* & *x162*)

S13 IF (*x161* &*x162*) THEN MATERIAL PROCESSING MDk (*Y11 = Ln* & (*x161* & *x162*) => *x153 = Y161*)

S14 IF *x153* THEN ($Y15 = L_{bn}$) & ($Y162 = (x = (L_{bi}, L_{CB}) - Ln)$)

S15 IF (($Y15 = L_{bn}$) & ($Y162 = ((L_{bi}, L_{CB}) – Ln)) =$ *x171*))) THEN IDENTIFY (($Y171 = L_{bi} = \Sigma\ Ln$, $x \le p_a$) OR ($Y171 = L_{bi} > Ln$, $x > p_a$) OR ($Y172 = L_{CB} = Ln$, $x = p_a = 0$) OR ($Y172 = L_{CB} > Ln$, $x = L'_{CB} > p_a$))

S16 IF (*Y171* & *Y172*) REPEAT S12 … S15 AS FAR AS TO EXHAUST CRM1;

S17 IF ((*Y171 = x181*) & (*Y172 = x182*)) THEN IDENTIFY AND SELECT AND MARK LABEL KTL_{CB};

S18 IF *Y181 = Ln* THEN GO TO CRM3 – *x20* ELSE $Y182 = x \le p_a$ GO TO *x21* ELSE $Y183 = L'_{CB}$ GO TO CRM2;

S19 IF *Y183 = x19* THEN CRM2 GO TO RCBk – *Y19 = x133*;

S17(1) IF *Y171* THEN x51; **S17(2)** IF *Y172* THEN *x61*.

5. CONCLUSIONS

The optimization process resulted in a soft product made up of a NC program and an optimization program, which was designed and applied and which operates in a real manufacturing environment. This program allows the minimization of material losses in the consumption of profiles made of expensive materials, reducing the losses, which condition the Kanban Process.

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