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CHARACTERISTICS AND CLASSIFICATION OF THE ANNUALISED WORKING HOURS PLANNING PROBLEMS[1]

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Abstract

Annualising working hours (i.e., the possibility of irregularly distributing throughout the year the total amount of the employees working hours) is one of the means to face the seasonal nature of the demand. Annualising working hours provides much flexibility to the production system (which is one of the main principles of *lean production*), so the company is allowed to plan the staff working time more efficiently. However, doing irregular working weeks implies a worsening of the working conditions that could be compensated by reducing the workers annual working time. On the other hand, conditions are provided in order to avoid an excessive workers' overburden in long periods of strong demand. This paper introduces annualised hours (AH) as a mean to achieve production flexibility and proposes a classification scheme of the annualised working hours planning problems that arise in services and in manufacturing, as well as an approach for solving them by using mixed and integer linear programming and assessing the benefits of introducing AH.

Keywords: Annualised hours, Flexibility, Lean production, Manpower planning, Service industry, Integer programming.

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1. Introduction

Nowadays *lean production* philosophy [1] is quite extended in industrial world and tends to be introduced in all kinds of production systems; especially, there is an increasing interest for the application of the management techniques of *lean production* to services [2].

Production flexibility is one of the main principles of *lean production* [3]. This flexibility is especially useful for organizations that have to face the seasonal nature of the amount and the composition of the demand, since they have basically two ways: (1) to accumulate inventory (if it is possible) when the demand drops and use it later to face the peaks of the demand (the inconvenience is that this may involve a high cost), and (2) to endow the company with enough flexibility to adjust the production capacity to the demand.

Production flexibility or, as it is said in [4], "the quickness and ease with which plants can respond to changes in market conditions" has been proclaimed, since middle eighties, as the best competitive tool for the manufacturing companies as well as service firms, which manage in a turbulent market.

There are many kinds of variability or fluctuations (regarding the demand, the supplier delivery time, etc.); therefore, there are many kinds of flexibility and, for each one, a great deal of ways to obtain it. Among them, Gerwin [5] defines volume flexibility as “the ease with which changes in the aggregate amount of production of a manufacturing process can be achieved”.

On the other hand, and as it is pointed out in [6], one of the main sources of volume flexibility is the flexibility of the human resources. This statement is particularly true in many service industries, since the only option they have to adapt on demand is to increase or to diminish the number of present workers in the working place (to store inventory is, in that case, impossible). In this way, these companies could adapt the time of the workers’ presence or adapt the number of workers of the company, but this last option has usually some bigger costs. In some manufacturing companies, the flexibility of the human resources (whenever the other resources are not a limitation) allow these companies to be able to adapt their production capacity to the variations of the demand and then reduce their inventory levels and their costs. Also, the worker’s versatility (capacity to carry out different types of task) can provide flexibility to face the fluctuations in the composition of the demand.

There are different forms of achieving this flexibility in the human resources. The flexible firm model of Atkinson of 1985 [7] consists of a structure involving the division of labour force into peripheral (or numerical flexible) groups of workers clustered about a numerically stable core group, which conducts the organisation’s specific activities. Some authors, as Oke [8], notice that these combinations can end in some low productivity and quality levels.

Hiring and firing as a source of flexibility to face the demand variations is a possibility (with many inconvenients) that is represented in some of the aggregate production planning mathematical models. Some of them could be: HMMS or linear rules model [9], Jones' model, described in [10], and some planning linear programs [11].

Annualising hours (AH) is one of the possible ways of achieving the harmonization between the demand and the capacity and consists in distributing throughout the year the total amount of the staff’s working hours. This way, each worker can carry out

different working weeks throughout the year and the company can plan the longest working weeks in high demand periods and the shortest in low demand periods.

The flexibility associated to AH allows the firm to plan the working time in a more efficient way. The staff (or the capacity associated to the staff) can be adapted to the variations of the demand. This flexibility is highly desirable for service firms as well for manufacturing companies. By implementing AH, the company can reduce the cost due to overtime, temporary workers, lost demand and inventory and improve the product quality and the productivity and, therefore, the competitiveness. For example, in [12] an AH real case is exposed; in an agricultural machinery organization, the main results have been a diminish of 94% in the overtime cost and 53% in the use of temporary workers.

Annualising hours is one of the sources of flexibility that is taking more importance. The number of firms that are agreeing AH contracts is rising more and more. However, and in spite of its growing importance, the problems raised by AH (as, for example, the distribution of the working time throughout the year), have been little studied up to now. Consistently, a description and a classification of these problems seems to be essential.

The paper is organised as follows. Section 2 introduces annualised hours and its importance; section 3 proposes a classification scheme to differentiate the annualised working hours planning problems; in section 4 it is suggested a technique to develop effective planning procedures; and, finally, section 5 contains the conclusions.

2. Annualised hours (AH)

Although some early antecedent of AH can be found (for example, in 1956 three hundred workers of Sevalco, in Avonmouth (UK), were employed on a shift system based on AH), the first significant cases of AH date from the seventies, when some French, German and Scandinavian companies, began to use this kind of contract [13]. However, their use did not become extensive until the final eighties, when its use began to grow, mainly in the service sector. In 1993, the 6% of the workers of the UK had this type of contract [14], being the second most common form of non-standard working arrangement and, in 1996 [13], the 10% was reached.

With the aim to explore the applicability of different enablers of labour capacity flexibility, Oke [8] identifies some of them and carries out a survey to more than 500 manufacturing plants of the UK. The enablers identified are: overtime, part-time, temps, job sharing, annual hours, subcontracting, contract employees, varying lead times and rejecting orders. In the results of the survey, approximately the 40% of the companies considers AH as one of the most desirable options, mainly, because its low cost; however, it is still presented as a not very used option (around 10%).

The main inconvenience that AH presents is that the realization of irregular shifts implies, in general, a worsening of the working conditions, not accepted neither by the workers neither by the unions. This worsening could be compensated with a total reduction of the working time or with money, among others. On the other hand, the diverse bounds and rules (established as much in the law as in the collective bargain or firm agreement) that should usually respect the distribution of the working time throughout the year, avoid overloading the workers in excess in peak demand times. For example in France, the Aubry II or the “35 hours” law, establishes basically a reduction of the working time to 35 weekly hours (on average), without wage reduction, in exchange for permitting AH, subject to diverse rules. Some similar laws are claimed in other European countries. In most of the countries there is the possibility, by means of the collective bargaining, of reaching agreements between the firm and the workers to reduce working time in exchange for annualising it. The growing companies’ flexibility need, as well as the working time reduction historical tendency, makes foregone a considerable increase in the number of this type of agreements.

When working time is annualised, is necessary to carry out a planning of the working time of the workers throughout the year. If the firm made decisions without considering a long enough temporary horizon, situations of important deficit of presence in some weeks (which force to carry out a lot of overtime or to hire many temporary workers) or situations with the possibility that an employee does not work the number of annual hours specified in the contract would happen. On the other hand, the group of restrictions (more or less complex) that should usually respect AH implies a difficulty to find an optimal working time planning.

On the other hand, when a working time reduction (without wage reduction) accompanies AH, the unitary labour costs increase. The company should analyse if

this increase is compensated with the decrease of other costs, as the ones due to overtime, inventories, etc. Then, it is necessary to have procedures that allow the firm to quantify these costs.

Besides being necessary, the working time planning (the week working time, the overtime, the need of subcontracting, etc.) allows the firm to evaluate how the costs diminish when the working hours are annualised.

This way, it is necessary to have a classification of the different AH planning problems and to have procedures that allow carrying out the working time planning in an optimal way (this could mean minimizing the costs or maximizing the benefits). This would allow the company to evaluate the convenience of introducing an annualised hours scheme. The procedures should be designed from an appropriate way to each type of problem or case.

3. Classification

It is necessary to analyse the characteristics of the annualised working hour planning problems in order to develop appropriate resolution procedures. The study of real cases and the analysis of the normative mark (laws and collective bargains) has allowed us to identify different elements or characteristics to be considered in the classification. Next, each one of them is commented and a summary table is included with the proposed nomenclature (Table 1).

3.1. Types of products (*PR*)

The nature of the product or products is one of the most important characteristics since substantially different models can derive. Concretely, the product could be non-storable (*NS*), as it happens in the service sector, or could be storable, as it usually happens in the industry. In the last case, also, the products could be non-perishable (*S*) or perishable (they only could be stored during certain time), as it could be the case of some food (*SP*).

3.2. Nature of the productive process (*PS*)

The nature of the productive process should be also kept in mind, especially in which refers to the form in which the personnel intervenes in this process.

In some cases (generally in the industry) the process requires the simultaneous presence of all the members of the team, which implies that all should complete the same schedules (*SP*). In these cases, the productive capacity throughout the time of presence of the team stays constant.

In other (in many services), the productive process only requires the direct intervention of a person (supposed a certain infrastructure) and, consequently, the process can have a variable number of present workers throughout the time. In these cases, the productive capacity in each moment is essentially proportional to the number of present workers (it is what happens, for example, in a retail outlet). Then, the number of hours of presence in one period (one week, for example) can be different for some or other workers (*IP*).

3.3. Type of flexibility (*FX*)

The consultation of the law, the experts and the different agreements has resulted in five substantially different methods in the application of the AH:

(1) Bounded weekly working hours (*BW*): every week, any number of hours between a lower and an upper bound can be planned.

(2) Predetermined working week types (*PD*): the duration of the working week must belong to a determined list and, also, the annual number of weeks of each type could be fixed or bounded (for example, the duration of the working week must be 25, 35 or 45 hours and, in a year, each worker should carry out 16 weeks of 25 hours, 21 weeks of 35 hours and 9 weeks of 45 hours).

(3) Flexible hour grant (*FHG*): the workers usually carry out a regular working week, but in one year the use of a certain number of flexible hours is permitted. These hours will be compensated with rest (for example, working

in some weeks fewer hours than the usual).

(4) Flexible week grant (*FWG*): in a certain number of weeks a year, the determination of working weeks with a number of hours superior or inferior to the usual is permitted.

(5) Intervals (*INT*): some possible intervals for the working week are settled down and, also, the number of weeks in a year with a number of worked hours belonging to each interval is bounded; for example, the number of weeks a year in which a worker does between 25 and 35 hours must be at least 20 weeks and no more than 30 weeks, and the number of weeks a year in which a worker does between 35 and 45 hours should be included between 20 and 26.

3.4. Cross-trained workers (*CTW*)

In a service company there may be several types of task or works and diverse categories of workers. If each category performs only one type of task, and each type of task is performed only by one category, then the working time planning problem could be separated into types of task (*NCT*). It can also happen that a category could perform its types of task and others belonging to inferior categories (*HCT*). Finally, it can happen that a table [categories/types of task] indicating which types of task each category can perform (and, also, the yield realizing the task) can be defined (*CT*).

The case of hierarchical versatility (*HCT*) is, in fact, a particular case of the last case (*CT*), so it has been included inside this. This way, we only distinguish the cases *NCT* (the workers can perform only one type of task) and *CT* (the workers are cross-trained).

Of course, in *CT* case, for each category, priorities associated to the different types of task that is able to carry out could be defined (although the workers were cross-trained, it could be preferable to assign them some types of task before others); also, its yield in the realization of certain tasks could be inferior to the obtained in other one.

3.5. Conditions imposed to the solution (*CND*)

Besides the characteristic constraints of the AH, other conditions that could be derived from a law, from an agreement between the company and the workers or from the requirements of the productive system must be respected. Most of these restrictions are established in order to avoid an excessive overloading of the workers in strong demand periods:

(1) Minimum requirements (*MR*): this condition is related with the service level that offers the company. Although the system is sized to cover the whole demand and to offer a good service level, in some weeks this cannot be possible due to very high peaks in the demand or many workers doing their holidays. In these cases, an inferior service level can be accepted, provided that a minimum level is satisfied. The company could measure this minimum service level (minimum requirements) in weekly hours of presence or, for manufacturing companies, in product units (for example, for one week with a demand of 200 units of certain product, a minimum of 180 units must be satisfied).

(2) Mean in a group of consecutive weeks (*MGW*): the mean of worked hours in a certain number of consecutive weeks, L, should not be superior to h_L hours/week (this is a rule settled down in Aubry II law, with L=12 weeks and h_L=44 hours/week).

(3) Strong weeks (*SW*): in one year, and for each worker, the number of weeks in which the worked hours overcome a given value (h_A hours) should not exceed a specific value (A weeks).

(4) Weak weeks (*WW*): in one year, and for each worker, the number of weeks in which the number of worked hours is inferior to a given value (h_B hours) should be at least a specific value (B weeks). Of course, notice that it could be an upper bound for the number of weak weeks.

(5) Blocks (*BL*): for each worker, if the average of worked hours in a group of E consecutive weeks (8, for example) exceeds a given value h_E (for example, 43 hours/week) then, during the e following weeks (for example, 2) the average of working hours must be inferior to h_e hours/week (30 hours/week, for example).

3.6. Demand satisfaction (*DS*)

In some cases it is considered that the demand should be covered in each period (*CD*), resorting if it is necessary to subcontracting, overtime or, for manufacturing firms, even subcontracting part of the production to similar companies. In other cases, it could be accepted that in some periods part of the demand cannot be covered. In this case, lost demand (*LD*) or differed demand (*DD*) can be considered.

3.7. Overtime regulation (*OR*)

Another aspect that influences in the problem definition is the fact that overtime could be permitted (*Y*) or not (*N*). In the first case, it is important to know its regulation: first, it should be known what is considered as overtime; second, in a year or week and for each worker, the upper bound of the overtime hours should be considered; and, third, the compensatory system or retribution for this kind of hours should be known (either monetary or with rest).

3.8. Possibilities of hiring temporary personnel (*HR*) / subcontracting production (*SC*)

Another important characteristic is the fact that temporary personnel's hiring (or, for manufacturing companies, subcontracting production to similar companies) to take charge of the demand that cannot be covered by the staff could be considered (*H*) or not (*NH*). Although the law permits it, it may not be advisable because of reasons related to the product quality or the difficulty of managing certain machines, etc. When external hiring of services or staff is permitted, some limitations could be established; besides the costs, the associate limits: maximum percentage regarding the staff, maximum number of hired hours, etc. should be known (for manufacturing companies, maximum quantity that is possible to subcontract).

3.9. Holidays (*HOL*)

Normally, holidays are negotiated and outside the reach of the annual working time

planning (*FH*). However, could be advantageous to propose the weeks (given some rules) in which the workers should carry out their holidays (*NFH*).

3.10. Solution evaluation criteria (*SEC*)

The economic criteria is the one that usually takes more importance to consider that a planning is optimal (*EC*). However, other criteria could be kept in mind (in a hierarchical way as well as weighting the different criteria in one function):

(1) Regularity of the working time throughout the year (*R*): this could minimize the worsening of the labour conditions.

(2) Equal distribution of the overtime (*EQ*): overtime implies, generally, larger retribution and its non equal distribution could result in inequalities among the workers.

(3) Suitability in the assignment of tasks to categories (*SA*): in cases in which versatility exists and the categories have associated a priority to the types of tasks that can carry out, it could be desirable to maximize an indicator of the suitability in the assignment of categories to working types.

For example, in [15] is exposed a case that consists in solving the problem minimizing the costs of overtime and subcontracting and, next, obtaining, for each worker, a new planning with a more regular working time distribution and with the same cost as the first planning.

3.11. Summary table and codification of problems

In Table 1 the proposed classification is summarized and a notation or code for the different values that can take the different characteristics considered is included.

Characteristic	Cod.	Description	Associated data
Type of products (PR)	*NS*	Non Storable.	
	S	Storable (non-perishable goods).	
	SP	Storable (perishable goods).	Maximum storable time.
Type of process (*PS*)	*SP*	Single planning.	Available weeks.
	IP	Individual planning.	Set of employees and their available weeks.
Type of flexibility (*FX*)	*BW*	Bounded	Lower and upper bound of the working weekly hours, for every week and every worker.
	PD	Predetermined working week types.	Set of possible working weeks and annual number (or bounds) of weeks for each type.
	FHG	Flexible Hour Grant.	Maximum number of flexible hours.
	FWG	Flexible Week Grant.	Maximum number of flexible weeks.
	INT	Interval.	For each worker: set of permitted intervals for each week; lower and upper bounds for the annual number of weeks that working week belongs to each interval.
Cross-trained workers (*CTW*)	*NCT*	No cross-trained workers.	For each category, type of task that is able to perform.
	CT	Cross-trained workers.	Table including which tasks could perform each category, and the priority and yield associated.
Condition (*CND*)		Minimum requirement (*MR*), mean in a group of consecutive weeks (*MGW*), strong weeks (*SW*), weak weeks (*WW*) and blocks (*BL*).	*MR*: Minimum demand to be covered *MGW*: L, h_L *SW*: A, h_A *WW*: B, h_b *BL*: E, h_E, e, h_e
Demand satisfaction (*DS*)	*CD*	Covered demand.	Subcontracting costs.
	LD	Lost demand.	Rupture costs.
	DD	Differ demand.	Differ costs and maximum number of weeks that is permitted to differ.
Overtime regulation (*OR*)	*Y*	Overtime is permitted.	Which hours are considered as overtime, which are the bounds in their performance and how are these hours compensated (retribution, rest).
	N	Overtime is not permitted.	
Hiring or subcontracting (*HR-SC*)	*H*	Hiring temporary people or subcontracting production is permitted.	For each type of task or product: hiring or subcontracting costs and bounds (if necessary).
	NH	Hiring temporary people or subcontracting production is not permitted.	
Holidays (*HOL*)	*FH*	Fixed holidays.	For each worker, non-available weeks.
	NFH	Non-fixed holidays.	Rules associated to the holidays (i.e. three consecutive weeks in summer).
Solution evaluation criteria (*SEC*)	*EC*	Economic criteria (maximize benefits / minimize costs).	Unitary income and overtime costs, hiring temporary workers costs, inventory costs, rupture costs, etc. and weights granted to each one of them.
	R	Regularity of the working time throughout the year.	For each worker, average of weekly working hours.
	EQ	Equal distribution.	
	SA	In the case of cross-trained workers, to maximize an indicator of the suitability in the allocation of tasks to categories.	

Table 1. Classification of the annualised working hours planning problems

The classification and the proposed notation allow the description and identification (using a code) of each type of problem. The symbols used in the next suggested code have the following meaning:

/	used as a characteristic separator.
|	used as a separator when the characteristic should take a value among several.
,	used as a separator when the characteristic can take more than one of the associated values.
{}	used to indicate that the characteristic is optional, that is to say, that this can take none of the associated values.

Considering the classification, the annualised working hours planning problems could be coded in the following way: **[a / b / c / d / {e} / f / g / h / i / {j}]**

Where each letter refers to a characteristic and can take the following values:

$a\ (PR) \rightarrow NS \mid S \mid SP$

$b\ (PS) \rightarrow SP \mid IP$

$c\ (FX) \rightarrow BW \mid PD \mid FHG \mid FWG \mid INT$

$d\ (CTW) \rightarrow NCT \mid CT$

$e\ (CND) \rightarrow \{MR, MGW, SW, WW, BL\}$

$f\ (DS) \rightarrow CD \mid LD \mid DD$

$g\ (OR) \rightarrow Y \mid N$

$h\ (HR\text{-}SC) \rightarrow H \mid NH$

$i\ (HOL) \rightarrow FH \mid NFH$

$j\ (SEC) \rightarrow \{EC, R, EQ, SA\}$

It should be kept in mind that, obviously, not all the combinations are possible. There exist some non-possible combinations. There are some incompatibilities, as for example: if ($b = SP$) then ($j \neq EQ$); that is to say, if there is a single planning (all workers have the same working weeks), it does not make sense to find a distribution (equal) that eliminates the inequalities among workers.

Finally, and as an illustrative example, the code corresponding to one of the AH

problems that are exposed in [15] is included: [*NS* / *IP* / *BW* / *CT* / *MGW,SW,WW,BL* / *CD* / *Y* / *H* / *FH* / *EC+R*]

The problem consists in planning the working time of each worker from part of a service company staff (therefore, the product is non-storable, *NS*, and an individual working time must be planned, *IP*). The workers could carry out working weeks of any duration, lower and upper bounded (*BW*). There are two categories, and the first one is able to carry out its tasks and the tasks of the second category (*CT*). The solution must satisfy the conditions *MGW, SW, WW* and *BL*. The demand should be covered in each period (week) of the planning horizon (*CD*) with the possibility of resorting to overtime (*Y*) as well as to hiring temporary workers (*H*). Holidays are fixed a priori (*FH*). And, finally, the solution must minimize the cost due to overtime and recruiting and then maximize the regularity of the working time throughout the year (*EC+R*).

The classification allows to define and codify thousands of problems. In the following section an approach for solving them is proposed.

4. Annualised working hours planning procedures

An instrument for solving the annualised working hours planning problem should provide the working time (in hours, for example) of each one of the workers in each one of the periods of the planning horizon (many of the conditions that should satisfy the solution force to take a year). Notice that the planning could be updated in order to adapt to the changes in the demand forecasts or to possible discrepancies between the planned and the realized working time. In that case, the planning horizon should correspond to the rest of the year. This way such conditions as *HW*, among others, could be considered. On the other hand, since there are other conditions that affect the weekly working hours, it is advisable to consider weeks as the periods in which the planning horizon is divided (although these periods could take shorter periods, this would increase unnecessarily the size of the problem).

Corominas and Pastor [16] propose mixed and integer linear programming (MILP) as the most appropriate technique to obtain an optimal annualised working hours planning keeping in mind the different restrictions imposed to the solution. Although

they notice that it is not possible to establish a general procedure to solve all problem types, the proposed approach is valid and appropriate for most cases. Here it is important to notice that there does not exist a unique MILP model, since each particular problem (characterized by the type of products, process, flexibility, constraints, etc.) needs a different model.

On the other hand, the MILP models associated to some specific problems that could result from the proposed classification have been tested. In the computational experiments, very satisfactory times of resolution have been obtained for big size models (even for 500 workers). For example, in [15] the model of a particular case as well as the obtained times of resolution in a computational experiment are detailed, being these times very satisfactory for cases of realistic sizes. Concretely, and following the proposed nomenclature in the problem classification, it is the case described in the previous section as [*NS* / *IP* / *BW* / *CT* / *MGW,SW,WW,BL* / *CD* / *Y* / *H* / *FH* / *EC+R*]. Also, in [17] the models and the realized experiment are described for the [*NS* / *IP* / *PD* / *NCT* / *MGW* / *CD* / *Y* / *H* / *FH* / *EC*] case. Finally, in [18] and [19] the models and the computational experiments of [*NS* / *IP* / *PD* / *CT* / *MGW, SW, WW* / *LD* / *N* / *NH* / *FH* / *R*] and [*S* / *SP* / *BW* / *NCT* / *MGW, SW, WW* / *DD* / *Y* / *H* / *FH* / *EC*] problems are detailed. Solving working time and production planning under annualised hours shows how capacity is adapted to demand. Also, if an AH system is compared to a traditional system (regular working hours), it can be seen how the costs due to overtime, temporary workers, subcontracting, lost demand and, in some cases, inventory, are diminished.

5. Conclusions

Annualising hours has been shown as one of the best forms of adapting the productive capacity to the demand fluctuations. AH avoids that a proportion of the potential capacity gets lost because it does not temporarily coincide with the demand (in the case of service companies), and reduces the inventory levels (in the case of manufacturing companies). AH could be considered as a management technique useful for a *lean production* approach.

On the other hand, with a system of this type, and when the distribution of the working time throughout the year must comply with some, more or less complex, conditions, a planning is essential to be carried out.

The different conditions that should satisfy the planning imply a difficulty in finding the optimal solution. Then, effective procedures should be designed for each type of problem. These allow companies to evaluate the convenience of implanting annualised hours in exchange for reducing the total working time of the affected staff members or for offering economic compensations.

In spite of the growing importance that AH is taking, this has been little studied from the quantitative point of view. In this work, a synthesis of the characteristics of the annualised working hours planning problem is exposed. This paper also proposes a classification and codification of the different problems (the first, to the best of our knowledge) that will help the development of specific resolution procedures.

Finally, mixed and integer linear programming (MILP) has been suggested as the most appropriate resolution technique. MILP allows considering the different restrictions, assures the optimal solution and, also, has been validated as an operative procedure in the resolution of some of the problems that arise from the proposed classification.

Nowadays, computational experiences (solving some of the classified problems) are being carried out and satisfactory results are being obtained.

References

[1] WOMACK, P.; JONES, D. (1998). *Lean Thinking*. Touchstone Books.

[2] CUATRECASAS, L. (2002). Design of a rapid response and high efficiency service by lean production principles: Methodology and evaluation of variability of performance. *International Journal of Production* Economics, 80, 169-183.

[3] CARRETERO, L.E.; LÓPEZ, J.I.; DELGADO, L.M. (2000). Word class manufacturing in Spain. Analysis of the application of the lean production system in spanish industry.

Proceedings of the First World Conference on Production and Operations Management (POM), Sevilla, 27 August to 1 September 2000.

[4] COX, JR., T. (1989). Towards the measurement of manufacturing flexibility. *Production and Inventory Management Journal*, First Quarter, 68-72.

[5] GERWIN, D. (1987). An agenda for research on the flexibility of manufacturing processes. *International Journal of Operations and Production Management*, 7, 1, 39-49.

[6] SLACK, N. (1991). *The Manufacturing advantage*. Mercury Books.

[7] ATKINSON, J. (1985). Flexibility planning for an uncertain future. *Manpower Policy and Practice*, summer, 1.

[8] OKE, A. (2000). Linking human resource flexibility with manufacturing flexibility: enablers of labour capacity flexibility in manufacturing plants. *Proceedings of the First World Conference on Production and Operations Management (POM)*, Sevilla, 27 August to 1 September 2000.

[9] HOLT, C.C.; MODIGLIANI, F.; MUTH, J.M.; SIMON, H.A. (1960). *Planning, Production, Inventories and Work Force*. Prentice-Hall.

[10] BUFFA, E.S; TAUBERT, W.H. (1972). *Production-Inventory Systems*. Irwin.

[11] HAX, A.; CANDEA, D. (1984). *Production and Inventory Management*. Prentice-Hall.

[12] VILA, G.F.E.; ASTORINO, J. M. (2001). Annualized hours as a capacity planning tool in make-to-order or assemble-to-order environment: an agricultural implements company case. *Production Planning & Control*, 12, 4, 388-398.

[13] GALL, G. (1996). All year round: the growth of annual hours in Britain. *Personnel Review*, 25, 3, 35-52.

[14] HUTCHINSON, S. (1993). The Changing Face of Annual Labour. *Personnel Management*, April 1993, 42-44.

[15] COROMINAS, A.; LUSA, A.; PASTOR, R. (2002). Using MILP to plan annualised hours. *Journal of the Operational Research Society*, 53, 1101-1108.

[16] COROMINAS, A.; PASTOR, R. (2000). Manpower planning and scheduling in services with seasonal demand. *I World Conference on Production and Operations Management*; Sevilla, 27 de agosto al 1 de septiembre de 2000.

[17] COROMINAS, A.; LUSA, A.; PASTOR, R. (2002). Planning annualised hours with a finite set of weekly working hours and joint holidays. *Working paper*, IOC-DT-P-2002-16, Universitat Politècnica de Catalunya; Barcelona.

[18] COROMINAS, A.; LUSA, A.; PASTOR, R. (2002). Planning annualised hours with a finite set of weekly working hours and cross-trained workers. *Working paper*, IOC-DT-P-2002-22, Universitat Politècnica de Catalunya; Barcelona.

[19] COROMINAS, A.; LUSA, A.; PASTOR, R. (2003). Using a MILP model to establish a framework for an annualised hours agreement. *Working paper*, IOC-DT-P-2003-01, Universitat Politècnica de Catalunya; Barcelona.