

# *E–aplan: a tool for teaching collaborative aggregate production planning in industrial engineering*

# *E–aplan: una herramienta para la enseñanza de la planificación colaborativa de la producción agregada en ingeniería industrial*

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## Abstract

*In this paper, we present a software tool entitled E–aplan Express (version 2018), with free access for educational and commercial use, to the modelling and resolution of aggregate production plans generating medium-long term production planning, based on a forecasted demand in that period. E–aplan tool models the aggregate production plan through a mixed integer linear programming model (MILP). The LP solver optimization engine generates the planning by adjusting all the optimization variables with the least possible error. Finally, it is presented an illustrative example that considers a collaborative aggregate production planning, in a two-echelon supply chain. Different scenarios are modelled in order to simultaneously consider the planning objectives of both enterprises of the network.*

*En este trabajo se presenta una herramienta informática titulada E–aplan Express (versión 2018), de libre acceso para uso educativo y comercial, para la modelización y resolución de planes de producción agregados generando una planificación de la producción a medio-largo plazo, en base a una demanda prevista en ese periodo. La herramienta E–aplan modela el plan de producción agregado a través de un modelo de programación lineal entera mixta (MILP). El motor de optimización LP solver genera la planificación ajustando todas las variables de optimización con el menor error posible. Por último, se presenta un ejemplo ilustrativo que considera una planificación de la producción agregada colaborativa, en una cadena de suministro de dos eslabones. Se modelan diferentes escenarios para considerar simultáneamente los objetivos de planificación de las dos empresas de la red.*

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Keywords: planning, aggregate production, collaborative, industrial engineering students  
Palabras clave: [planificación](#), [producción agregada](#), [colaborativa](#), [estudiantes de ingeniería industrial](#)

## 1. Introduction

Production and operations management courses are extensively contained in the universities of industrial engineering. The study of operations management and their applications in the industrial engineering has resulted in numerous contributions both to the knowledge of models (linear programming) and to the development of specific tools (Mula and Poler, 2011; Poler et al., 2013; Andres et al., 2016) and methods, allowing students to effectively organise the production and distribution of goods with the aim of minimising the cost of the resources needed to meet the demand.

The production and operations management planning system consist of a set of hierarchically structured planning subsystems that include aggregate production planning (APP), production master planning (PMP), materials requirement planning (MRP) and capacity requirements planning (CRP) (Jacobs et al., 2011; Pereira et al., 2020). Along the current paper, we are going to focus on the upper aggregation level, the APP. In this regard, general linear programming models are appropriate for addressing the APP, as long as the cost and variable relationships are linear, and demand can be managed as a deterministic. The solver option in a spreadsheet software can estimate the solution, although only one product family and one resource type can be considered. Moreover, companies such as SAP and Oracle offer more advanced planning options, as part of their enterprise resource planning systems, providing a toolbox with powerful applications that include functions to solve linear programming problems and other types of mathematical problems. Nevertheless, there is a lack free access tools to support the modelling and calculation of the APP, for its application in educational context of industrial engineering. Going further, and to the best of our knowledge, there are not open-source tools that allow modelling the negotiation process when a APP is calculated in a collaborative way between two enterprises of the supply chain, i.e. supplier and manufacturer.

In the light of this, this paper aims to introduce the *E-aplan Express* software to optimise aggregate plans. The aggregated planning optimizer software is applied in a case of study, in which two supply chain companies, supplier and manufacturer, collaborate to solve an aggregate plan from a centralised perspective. The aggregate plan is solved by the manufacturer considering the restrictions of the supplier. *E-aplan* allows to model and calculate different negotiation scenarios. The best solution will be the one in which the manufacturer considers the restrictions defined by the supplier, and an agreement is reached by both partners.

Accordingly, the paper is organised as follows: Section 2 presents the characteristics of an aggregate production plan. Section 3 introduces the software tool entitled *E-aplan Express*; in Section 4 describes the case study in which the proposed tool is applied. Section 5 presents different scenarios and the comparison of them according to the total costs computed for the aggregated plan. Finally, the conclusions are posted in Section 6.

## 2. Aggregate production planning

Aggregate production planning consists on moving the business plan in the medium-long term to the world of production, generating medium-long-term production planning, which is based on a forecast or estimate of the demand in that period, and based on productivity criteria, efficiency, pre-established and estimated capacity (Cheraghalikhani et al., 2019).

Accordingly, the production aggregate planning deals with planning capacity needs and availability to meet market needs, planning the materials for its on-time reception, in the correct quantity needed for production. APP specifies the production of units of product families and the production capacities required by types of resources, in each planning period along the planning horizon. The main objective is, therefore, to find the combination of resources and inventory levels that minimize production costs in the planning horizon. APP plans the production and use of resources, in aggregate units, to respond to the expected demand, taking into account the available capacity. The most used unit for product is the family, while the common resource is the labour (see Figure 1).



Figure 1 – Product families and labour resources

Aggregate planning techniques can be divided into (i) trial and error with a spreadsheet software; and (ii) linear programming (Jacobs and Chase, 2018). Spreadsheet software is a trial and error technique in which the calculation the APP model is based on developing alternative plans that represent different policies that can be improved by making specific modifications. Spreadsheet software is a simple technique making it the most used. Nevertheless, trial and error technique does not guarantee to obtain an optimum. With regards linear programming, is a technique that allows to minimize an objective function that relates production to the associated costs, and whose restrictions allow modelling the availability, resource capacity, demand to meet, etc. E-aplan software, hereafter introduced, is classified as a free access linear programming technique.

In the collaborative context, collaborative planning is considered as ‘an interactive process, in which the customers and suppliers of a value chain, continuously collaborate and share the information on demand to jointly plan their activities’(Alarcón et al., 2006). Collaborative Planning encompasses multiple planning domains (Dudek and Stadtler, 2005), extending the planning process that, initially, is local, to a context of several planning domains (Berezinets et al., 2020). For this, it is essential that there is an exchange of relevant data between the different planning domains and a plan that benefits everyone, based on mutual agreement, is obtained (Andres and Poler, 2016).

### 3. E-APLAN

E-aplan is an aggregated planning optimizer, characterised by being a free access for educational and commercial use tool. E-aplan optimises aggregated plans of types of products and types of resources, provides several options to adjust the types of plans to solve and provides easy importing and exporting features for legacy systems interoperability. The main objective of E-aplan is to generate planning to meet that expected demand, optimizing different variables, such as minimizing costs, minimizing variations in labour needs, minimizing the level of inventory of certain finished products or raw materials. The E-aplan optimization engine generates the planning by adjusting all the optimization variables with the least possible error.

Industrial engineering students can download E-aplan free access tool at the following link

<https://bit.ly/2ZgGgfX>. The user guide can be downloaded from help once E-aplan is installed (see Figure 2).

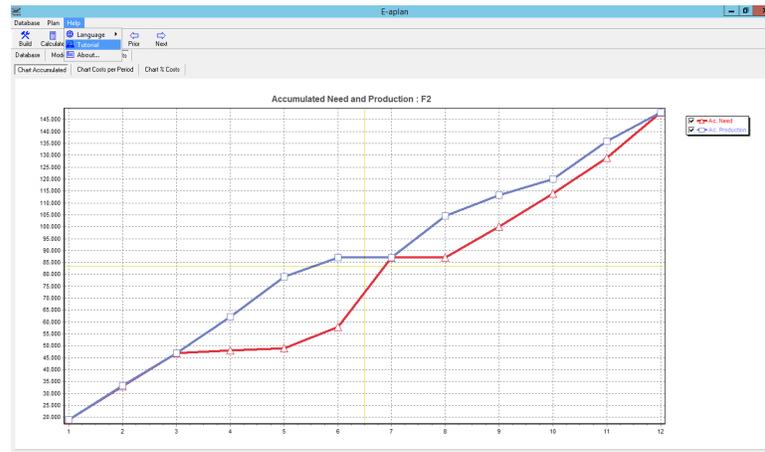


Figure 2 – E-aplan Express software tool

#### 4. Case study: furniture supply chain

The case study considers a furniture supply chain that consist of two levels, the *manufacturer* (E1) and the *supplier* (E2). The *manufacturer* produces two families of products, *family 1*: chairs, and *family 2*: tables. one type of labour, the *assembly labour* manufactures the two product families. E2 is the *supplier* of wood components and supplies two family of products: *family 1*: chairs wood components, and *family 2*: tables wood components. the supplier has one type of labour in charge of processing the components of the two families, the *carpenter labour* (see Figure 3).

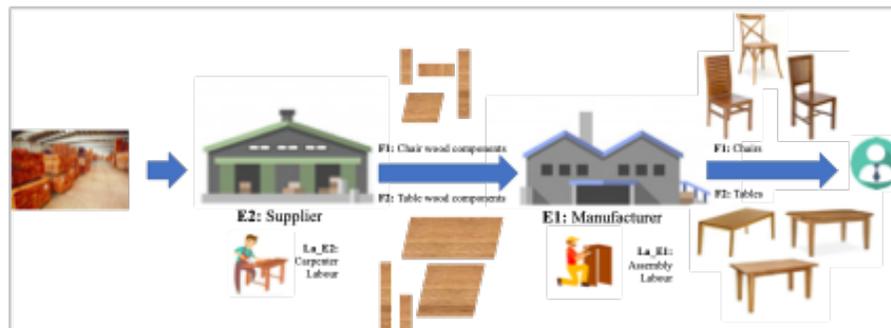


Figure 3 – Furniture supply chain

Given the complexity in the management of the CS and the sometimes-contradictory objectives of the entities belonging to the CS, such as distribution, planning, manufacturing and purchasing, it is convenient to develop a union scenario that captures the diverse objectives of the partners of the CS. In general, the integration of the functions of the different partners is the main objective of the supply chain planning (Gupta and Maranas, 2003). The main aim of the case study is to compute collaborative aggregate plan to help, facilitate and guide decision makers in the design of the collaborative planning process chain in a supply. The input data used in the case study refers to the products (Table 1), resources (Table 2), hours required to produce the families (Table 3), periods (Table 4) and demand (Table 5).

Product code	F1	F2
Product description	Family 1	Family 2
Material cost (per unit)	30	20
Stock handling cost (per unit and period)	1.2	1
Delay cost (per unit and period)	9	6
Subcontracting cost (per unit and period)	40	30
Initial stock	0	0

Table 1 – Product input data

Resource code	La.E1	La.E2
Resource description	Labour E1	Labour E2
Regular hours cost (per hour)	6	7
Extra hours cost (per hour)	9	10
Idle hours cost (per hour)	6.6	7.7
Increase / Hire resource cost (per unit)	600	700
Decrease / Fire resource cost (per unit)	900	1000
Minimum number of resources allowed	50	40
Maximum number of resources allowed	150	150
Capacity (hours per day)	8	8
Percentage of extra hours allowed	0.1	0.1
Initial resources	100	100

Table 2 – Resources input data

Product code	Resource code	Load (hours of resources per product unit)
F1	La.E1	0.3
F1	La.E2	0.4
F2	La.E1	0.5
F2	La.E2	0.6

Table 3 – Resources input data

Period code	Period description	Capacity (days per period)
1	January	20
2	February	20
3	March	22
4	April	20
5	May	22
6	June	21
7	July	20
8	August	22
9	September	22
10	October	20
11	November	21
12	December	20

Table 4 – Periods input data

Period code	Product code F1	Product code F2
1	20000	19000
2	15000	14000
3	15000	14000
4	2000	1000
5	2000	1000
6	10000	9000
7	30000	29000
8	1000	0
9	14000	13000
10	15000	14000
11	16000	15000
12	20000	19000

Table 5 – Demand input data

## 5. Collaborative aggregate production planning: scenarios

Collaborative planning involves a broad exchange of information and alignment of individual objectives with the overall objectives of the supply chain, which implies a clear difficulty. We will start with the non-collaborative scenario, by only considering the manufacturer objectives. Next, different negotiation rules are defined by the supplier, which are transmitted to the manufacturer to proceed with the calculation of the collaborative aggregate production plan. A set of seven scenarios are modelled in order to collaboratively compute the aggregate production planning in the furniture supply chain (see Table 6). *E–aplan* software automatically builds for each scenario a mixed integer lineal programming (MILP) model. The MILP model for an Aggregated Planning is automatically generated loading the data from database and applying the options defined for each scenario <https://bit.ly/37bic0D>.

	Description
Scenario 1	Centralised calculation of the APP. The manufacturer computes the APP, by only considering its objectives and restrictions, without taking into account the constraints defined by the supplier. Labour resources are integer.
Scenario 2	Collaborative centralised calculation of the APP. Supplier and Manufacturer determines that the production must be levelled
Scenario 3	Collaborative centralised calculation of the APP. Manufacturer and supplier agree with not to produce in extra hours
Scenario 4	Collaborative centralised calculation of the APP. Manufacturer and supplier agree with not to produce in extra hours. Supplier determines that the resources must be levelled
Scenario 5	Collaborative centralised calculation of the APP. The Manufacturer and supplier agree to produce in extra hours. Supplier determines that the resources must be levelled. The manufacturer suggests to the supplier to reduce the labour in 50 in periods 6, 7 and 8
Scenario 6	Collaborative centralised calculation of the APP. The Manufacturer and supplier allow to produce in extra hours. Supplier determines that the resources must be levelled. The manufacturer suggests to the supplier to allow a minimum decrease and increase of labour in 10
Scenario 7	Collaborative decentralised calculation of the APP

Table 6 – Description of the modelled scenarios

In Figure 4 there is depicted the *E-aplan* ‘Options’ view, that allows the decision makers to define the restrictions of both collaborative partners, the manufacturer, and the supplier. Figure 4 corresponds to the constraints defined in scenario 4, in which the number of resources is integer, and no extra production is allowed. Moreover, the editor of ‘Options’ window allows to model the supplier resources levelled.

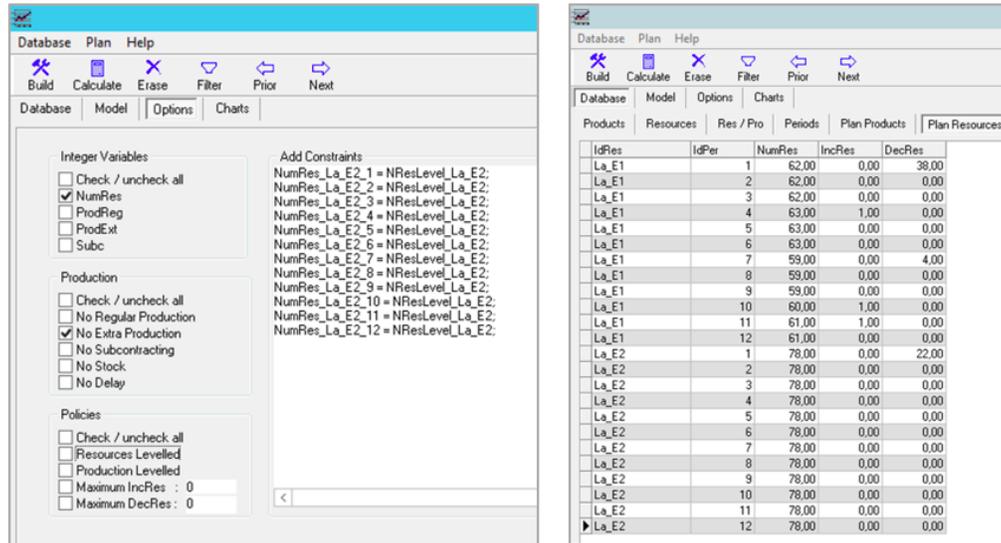


Figure 4 – *E-aplan* ‘Options’ and ‘Database’ windows

The results obtained in each scenario modelled are presented in Table 7. First column refers to the regular production cost considering the normal operation cost of the resource labour. Second column depicts the extra production cost when producing in extra hours are allowed. Subcontracting cost is 0 because none of the proposed scenarios need to employ a company outside the manufacturer and the supplier. Idle cost refers to the cost of having resource labour without working. Hire and fire cost refer to the costs associated with the employing or dispense labour resources. Inventory cost are the costs associated with the procurement, storage, and management of inventory. Delay cost refers to the cost of non-satisfying the demand in a certain period. Finally, the total costs result from the sum of the aforementioned costs. Total cost allows to compare the appropriateness of the aggregate plan considering all the scenarios. In this regard, the non-collaborative scenario, scenario 1, is the less costly because it only takes into account the manufacturer’s restrictions. The non-collaborative scenario obtains the best solution in terms of manufacturer costs, but it does not consider the supplier restrictions. Thus, when collaborating, the decision makers have to consider the restrictions defied by all the supply chain partners. The nodes of the supply chain are not competing, and the supply chain partners have to take into account all the objectives defined. The total cost is the minimum possible if the sum of the costs of each node is minimum, but it is not a competition between the nodes, in order to obtain the individual minimum cost. In this regard, if one partner only takes into account its cost, having the lowest possible cost, it is possible that this individual minimum cost is obtained at the expense of that other supply chain partners have higher costs. Thus, damaging the supply chain and reducing the level of service. When considering collaborative purposes, the best scenarios are the 3 and the 6. Now, the supply chain enterprises have to negotiate which of both scenarios are going to be applied for the aggregate plan calculation.

	Regular production cost	Extra production cost	Subcontracting cost	Idle cost	Hire cost	Fire cost	Inventory cost	Delay Cost	Total cost
Scenario 1	1783016	27068	0	3520	24400	84000	136128	16400	2074532
Scenario 2	1754295	68963	0	6355	3900	64800	151067	385000	2434379
Scenario 3	1801600	0	0	2561	28600	90000	137129	23333	2083223
Scenario 4	1801600	0	0	26752	1800	59800	118949	253088	2261989
Scenario 5	1769575	46656	0	67435	36000	95000	141003	105728	2261397
Scenario 6	1770120	45856	0	17706	24400	84000	135915	14800	2092796
Scenario 7	1784696	24200	0	0	45100	93000	241357	400	2188753

Table 7 – Costs of the aggregated plan per cost type obtained in each scenario

## 6. Conclusions

*E–aplan* Express software is presented as a free access for educational and commercial use, for modelling and solving aggregate production plans, according to a forecasted demand. The *E–aplan* is validated with a case study, of the furniture supply chain, to collaboratively compute the aggregate plan in seven different scenarios. The E–aplan is based on the automatically formulation of a **MILP** based on the restrictions defined by each of the collaborative partners. Some limitations found of using linear programming for the calculation of the **APP**, include: **(i)** the optimum of the (linear) model is obtained, but not that of the real system; **(ii)** there may be nonlinear functions in the real system, e.g. some costs, the productivity of workers that changes over time, etc.; **(iii)** qualitative restrictions can be difficult to introduce; **(ix)** the size of the problem can become excessive to be solved in a reasonable time. Nevertheless, as the hardware (processor) and software (solver) progress, larger problems could be resolved. Despite the aforementioned limitations, *E–aplan* provides a free access tool to compute aggregate plans with an efficient computational time, set in seconds. The appropriateness of using the tool for collaborative purposes of aggregate plans is widely demonstrated with the modelled scenarios.

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