Decomposing bills of materials using the Gozinto-list-method

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Abstract: This paper introduces a method for calculating material requirements by decomposing bills of materials. Starting with the primary (end customer) demand, we use bills of materials to calculate direct material requirements step by step for each production stage until the total material requirements have been calculated. The method proposed in this paper illustrates how the product structure influences material requirements and may thus be used in class to show students how material requirements can be calculated precisely. In addition, the method proposed in this paper may also be applied for calculating material requirements in practice.

Keywords: bills of materials; BoM; material requirements planning; MRP system; Gozinto-list-method.

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1 Introduction

Industrial companies regularly order, assemble and/or produce raw materials, components, intermediate products, subassemblies, and final products. Intermediate and final products, which themselves consist of intermediate products, components and raw materials, are the building blocks of subassemblies. To avoid disruptions in the production process, companies have to make sure that the materials required during production are available at the right time, in the right place, and in the required quantities.

Textbooks on production and operations management (POM) discuss several methods that support the planning of material requirements. Forecasting methods, for example, analyse past material requirements, try to identify patterns in the available time series, and use this information to predict future material requirements [see, for an overview, Silver et al. (1998) and Payne and Taylor (2007) as an example for the application of forecasting in the service industry]. Inventory control models, in turn, use given demand information (in the deterministic case demand rates, in the stochastic case a given demand distribution with first and second moments, for example) to calculate order quantities and order intervals (see, for example, Glock et al., 2014; Buxey, 2006).

Using forecasting methods is appropriate especially for companies producing to inventory and for items with small to medium value. If high-value products are produced to order, then using forecasting procedures may be inappropriate, as imprecise forecasts may lead to expensive excess stock or shortages. In this case, it may be better to use bills of materials (BoM) to calculate material requirements exactly.

Surprisingly, methods for calculating material requirements using BoM have received only little attention in POM textbooks so far. This is clearly a deficit of many POM textbooks, as a thorough discussion of BoM and methods for decomposing them helps students to understand how the structure of a product influences the manufacturing process and the planning of material requirements. Besides, being able to work with BoM may help students to calculate more precise material requirements in their future employment and to avoid unnecessary costs.

Material requirement planning (MRP) systems were introduced in the 1970s – and they have been employed widely in the 1980s – as a tool for calculating material requirements stepwise for the entire production process. Such systems evolved continuously over time to improve the entire business process by providing integration between all players among a supply chain involved in manufacturing a product. Manufacturing resource planning (MRP II) and enterprise resource planning (ERP) systems were the result of these evolutions (Pope and Perkins, 2008). However, as modern ERP systems are quite complex, giving students an introduction into the principles of ERP systems may be very time-consuming, and it may be inappropriate especially for introductory courses in POM (Vluggen and Bollen, 2005).

The paper at hand tries to close the gaps identified above by introducing the Gozinto-list-method, which is an easy-to-use tool for calculating material requirements by decomposing BoM. The Gozinto-list-method first illustrates the structure of the product graphically and then decomposes the BoM stepwise to calculate material requirements for each production stage until the total material requirements have been calculated. The method was first proposed by Vazsonyi (1962), who referred to a non-existent Italian researcher, Zeparzat Gozinto (‘the part that goes into’), and claimed that this researcher had developed the method. The Gozinto-list-method was then extended by several authors (see for example, Bloech et al., 2014; Buscher et al., 2013; Glock, 2014). The Gozinto-list-method has received a lot of attention especially in German POM textbooks (e.g., Günther and Tempelmeier, 2007; Hartmann, 2002; Kummer et al., 2013; Dyckhoff and Spengler, 2007), but there is not a single English textbook we are aware of that discusses this method. For this reason, the paper at hand provides a description of the state-of-the-art of the Gozinto-list-method, and is directed both to students in the field of production and operations management as well as to teachers in POM who are interested to use this method in class to illustrate how BoM may be used to calculate material requirements.

The remainder of this paper is structured as follows. Section 2 introduces the Gozinto-graph, which is a graphical representation of the structure of a product, and Section 3 shows how Gozinto-tables can be used to calculate material requirements. Section 4 describes three extensions of the method, and Section 5 summarises the paper.

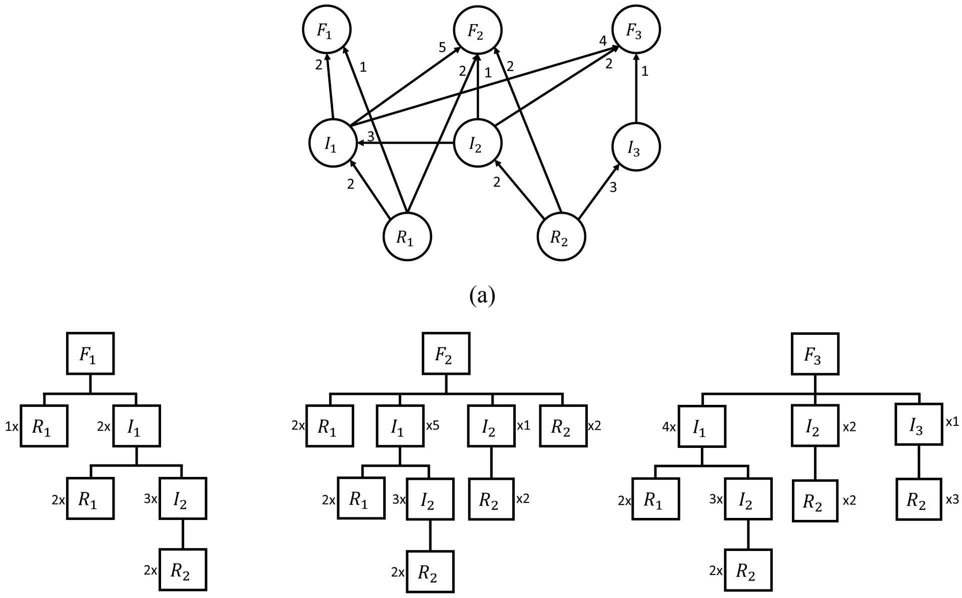
2 The Gozinto-graph

To calculate material requirements exactly, information on the structure of the product and the required production steps needs to be available. In industrial companies, information on the structure of a product can be available in different forms, e.g. in tables stored in the company's MRP system, in BoM, in product maps, or in production recipes.

This section introduces the Gozinto-graph as an easy-to-use tool for graphically illustrating the structure of a product. The Gozinto-graph is a directed and weighted graph that describes the quantitative input-output-relationships of all items entering and leaving a production process. As will be shown in more detail below, the Gozinto-graph is a compressed graphical structure that can summarise information of several BoM or product maps. Gozinto-graphs contain two elements: nodes and arrows. Both types of elements carry information about the input-output transformation process. Nodes represent items that are either required as input material (possibly purchased from an outside source) or that are produced by the company. The Gozinto-graph differentiates between three types of nodes: raw materials (i.e., nodes with no predecessors), intermediate products/components (i.e., nodes with predecessors and successors), and final products (i.e., nodes with no successors). To facilitate referencing to nodes, we assign numbers to the nodes in an ascending order, starting at the raw material stage and ending at the final product stage. The *arrows* of a Gozinto-graphs represent input-output-relationships, with the weights of the arrows indicating how many units of the subordinate product (start of the arrow) are required to produce one unit of the superordinate product (end of the arrow).

Figure 1 illustrates the Gozinto-graph [Figure 1(a)] and the corresponding structure of three products [Figure 1(b)] in an example. Suppose that two raw materials (R_1 and R_2) are required to produce three intermediate products/components (I_1, I_2 and I_3), which are then used to produce three final products (F_1, F_2 and F_3). As can be seen, the Gozinto-graph is a compact alternative to represent the structure of the products; instead of three BoM, only a single graph is required in the example presented in Figure 1.

Figure 1 (a) Example of a Gozinto-graph and (b) its corresponding product structures



(a)

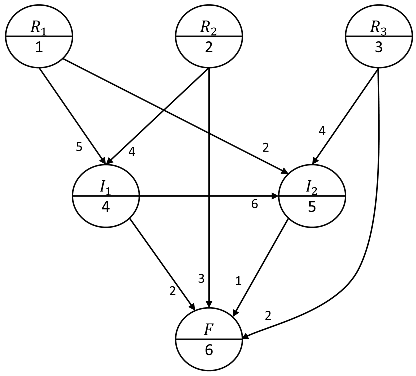
(b)

3 The Gozinto-list-method

This section introduces the Gozinto-list-method that can be used to decompose BoM and to calculate material requirements. The Gozinto-list-method requires information about the structure of the product and about the *primary demand*. The *primary demand* is the demand of the end customer, and it can extend both to final products and to components, where the latter may have been ordered as spare parts. The *secondary demand* refers to material requirements that are needed to produce the primary demand. Material requirements that cannot be assigned precisely to the production of one unit of a particular product, such as energy, lubricants or administrative support, for example, are referred to as *tertiary demand*, and they are excluded from further analysis. For a given product structure and for given primary demand information, the Gozinto-list-method calculates the secondary demand.

To illustrate the Gozinto-list-method, and to reduce the required calculation efforts, we consider in the following a simple example shown in Figure 2 where only one final product consisting of three raw materials and two intermediate products is produced. To illustrate the method, we assume that 200 units of the final product F and 100 units of component l_2 have been ordered. We use the Gozinto-list-method to calculate the secondary demand for this order. The Gozinto-list-method consists of two steps: First, we transform the Gozinto-graph into a Gozinto-list that systematically captures all input-output-relationships. Secondly, we use a calculation table to calculate the secondary demand.

Figure 2 Gozinto-graph used in the illustrative example



3.1 The Gozinto-list

In the first step of the Gozinto-list-method, the Gozinto-graph is transformed into a Gozinto-list. The Gozinto-list will make it easier to calculate the secondary demand in the second step of the method. The Gozinto-list is a table that consists of three columns, and each row of the Gozinto-list represents one arrow of the Gozinto-graph. Thus, the number of rows in the Gozinto-list equals the number of arrows in the corresponding Gozinto-graph, plus one row for the header. The first column of the Gozinto-list stores the reference number of the end node of an arrow, j, the second column stores the reference number of the starting node of an arrow, i, and the third column stores the weight of the arrow, d_{ij}. After transferring all arrows from the Gozinto-graph into the Gozinto-list, the Gozinto-list is sorted in ascending order of column j. Rows with the same j-value are sorted in ascending order of column i. Table 1 shows the Gozinto-list for the Gozinto-graph presented in Figure 2.

Table 1 Gozinto-list for the illustrative example

j	i	d_{ij}
4	1	5
4	2	4
5	1	2
5	3	4
5	4	6
6	2	3
6	3	2
6	4	2
6	5	1

3.2 Calculating secondary demands

In the second step of the Gozinto-list-method, the Gozinto-list developed in Step 1 of the procedure (Section 3.1) is used to calculate the secondary demands. The d_{ij}-values given in the Gozinto-list indicate how many units of product i are required to produce one unit of product j. This information can be used to calculate the secondary demand of subordinate products one after another for each step of the production process. The Gozinto-list-method uses a calculation table to compute the secondary demand step-wise starting with the arrow with the highest reference number j in the Gozinto-list. Table 2 illustrates the structure of the calculation table. The first column contains the reference number of the nodes of the Gozinto-graph. Subsequent columns contain information on $V_{k,i}$ (valence of node i), i.e. the number of outgoing arrows of a node that have not yet been considered in the current step of the procedure, and on $N_{k,i}$, i.e. the secondary demand of product i in step k of the procedure. As starting information for the Gozinto-list-method, the Gozinto-graph (and the corresponding valences of the nodes contained in the graph, $V_{0,i}$) as well as the primary demand $N_{0,i}$ of all products are required and entered into the calculation table.

To explain the calculation phase of the Gozinto-list-method, we introduce the following notations:

- n: number of items.
- n_r: number of raw materials.
- k: the current step of the Gozinto-list-method.
- d_{ij}: number of units of item i required to produce one unit of item j. d_{ij}-values not explicitly given in the Gozinto-list are assumed zero.
- $x_{ij} = 1$ if $d_{ij} > 0$, otherwise $x_{ij} = 0$.
- N: an array that represents the secondary demands of all items, i.e. N_i is the net demand of item i to satisfy primary demands

The pseudocode of the second phase of the Gozinto-list-method is as follow:

Step 1 $p = n$ and $k = 1$.

Step 2 While $(\sum_{i=1}^{n_r} V_{k-1,i} > 0)$ repeat the following:

Step 2.1 $V_{k,i} = V_{k-1,i} - x_{ij}$; $i = 1, 2,\ldots,p - 1$.

Step 2.2 $N_{k,i} = N_{k-1,i} + N_{k-1,p} * d_{ip}$; $i = 1, 2,\ldots,p - 1$.

Step 2.3 $N_p = N_{k-1,p.}$

Step 2.4 $p = p - 1$, $k = k + 1$.

Step 3 $N_i = N_{k-1,i}$,

In Step 2, each repetition adds one column with two sub-columns to the calculation table. The first sub-column stores the current values of the valences, while the second sub-column displays the current values of the secondary demands. Table 2 shows the calculation tables for the illustrative example. As can be seen, the secondary demand in the example is $N = [N_1 = 11{,}000$, $N_2 = 9{,}400$, $N_3 = 1{,}600$; $N_4 = 2{,}200$, $N_5 = 300$, $N_6 = 200]$.

Table 2 Calculation table used in the Gozinto-list-method

i	V_0^i	N_0^i		V_1^i	N_1^i		V_2^i	N_2^i		V_3^i	N_3^i
1	2	0	$p = 6$	2 – 0 = 2	0 + 200 * 0 = 0	$p = 5$	2 – 1 = 1	0 + 300 * 2 = 600	$p = 4$	1 – 1 = 0	600 + 2,200 * 5 = $\underline{11{,}600}$
2	2	0	$k = 1$	2 – 1 = 1	0 + 200 * 3 = 600	$k = 2$	1 – 0 = 1	600 + 300 * 0 = 600	$k = 3$	1 – 1 = 0	600 + 2,200 * 4 = $\underline{9{,}400}$
3	2	0	$N_6 = 200$	2 – 1 = 1	0 + 200 * 2 = 400	$N_5 = 300$	1 – 1 = 0	400 + 300 * 4 = 1,600	$N_4 = 2{,}200$	0 – 0 = 0	1600 + 200 * 0 = $\underline{1{,}600}$
4	2	0		2 – 1 = 1	0 + 200 * 2 = 400		1 – 1 = 0	400 + 300 * 6 = $\underline{2{,}200}$			
5	1	100		1 – 1 = 0	100 + 200 * 1 = $\underline{300}$						
6	–	$\underline{200}$									

Note: Secondary demands are underlined.

4 Extensions of the basic Gozinto-list-method

4.1 The Gozinto-list-method with feedback

One restrictive assumption in the basic Gozinto-list-method is that arrows occur only in one direction of the Gozinto-graph. In other words, products at a higher production level (e.g., final products) are never required for producing products at a lower production level (e.g., components). In practice, however, it is possible that the Gozinto-graph has arrows in both directions. Examples include the recycling of used or defective products, which are disassembled and then enter the production process again, or the chemical industry, where substances produced at higher production levels are sometimes used as catalysts at lower production levels. In the following, we use the term 'feedback' to refer to a situation where higher-level products are required to produce products at lower levels of the production hierarchy. We differentiate between two cases: In the case of *optional feedback*, using the higher-level product at an earlier step of the production process is optional. In the case of *obligatory feedback*, production of the product at the lower hierarchical level is only possible if the superordinate product is used. The Gozinto-list-method is extended in the following to the cases of optional and obligatory feedback.

Figure 3 Gozinto-graph with optional feedback

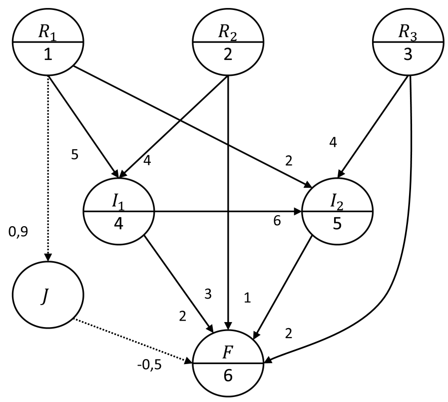


Table 3 Goznto-list for the Gozinto-graph with optional feedback

j	*i*	d_{ij}	*j*	*i*	d_{ij}
*J**	1	0.9	6	2	3
4	1	5	6	3	2
4	2	4	6	*J*	–0.5
5	1	2	6	4	2
5	3	4	6	5	1
5	4	6			

Notes: *Note that node *J* needs to be treated as an intermediate product. Therefore, it is added to the Gozinto-list and the calculation table after item R_1 and before the final product. In our example, we decided to enter it into the list before item I_1. Entering it after item I_2 would also have been possible, for example.

Table 4 Calculation table for the Gozinto-graph with optional feedback

i	V_0^i	N_0^i		V_1^i	N_1^i		V_2^i	N_2^i		V_3^i	N_3^i		V_4^i	N_4^i
1	3	0	$\begin{cases} p = 7 \\ k = 1 \\ N_6 = 200 \end{cases}$	3 – 0 = 3	0 + 200 * 0 = 0	$\begin{cases} p = 5 \\ k = 2 \\ N_5 = 300 \end{cases}$	3 – 1 = 2	0 + 300 * 2 = 600	$\begin{cases} p = 4 \\ k = 3 \\ N_4 = 2{,}200 \end{cases}$	2 – 1 = 1	600 + 2,200 * 5 = 11,600	$\begin{cases} p = J \\ k = 4 \\ N_4 = -100 \end{cases}$	1 – 1 = 0	11,600 + (–100 * 0.9) = <u>11,510</u>
2	2	0		2 – 1 = 1	0 + 200 * 3 = 600		1 – 0 = 1	600 + 300 * 0 = 600		1 – 1 = 0	600 + 2,200 * 4 = <u>9,400</u>		0	
3	2	0		2 – 1 = 1	0 + 200 * 2 = 400		1 – 1 = 0	400 + 300 * 4 = 1,600		0 – 0 = 0	1,600 + 2,200 * 0 = <u>1,600</u>		0	
J	1	0		1 – 1 = 0	0 + 200 * (–0.5) = –100		0	–100 + 300 * 0 = –100		0 – 0 = 0	–100 + 2,200 * 0 = –100		0	
4	2	0		2 – 1 = 1	0 + 200 * 2 = 400		1 – 1 = 0	400 + 300 * 6 = <u>2,200</u>					0	
5	1	100		1 – 1 = 0	100 + 200 * 1 = <u>300</u>								0	
6	–	<u>200</u>											0	

4.1.1 Optional feedback

Optional feedback occurs if a higher-level product can be used to produce a lower-level product, but using the higher-level product is not mandatory in the production process of the lower-level product. To illustrate the case of optional feedback, suppose that in the example presented in Figure 2, a second product J (for example scrap metal) emerges from the production process of the final product F, and that for each unit of F that is produced, 0.5 units of the second product J are produced as well. Let us assume further that product J can be recycled in such a way that one unit of product J can replace 0.9 units of raw material R_1 in the production process. Obviously, feedback between the final product F and raw material R_1 occurs in this case. The feedback is optional, however, as production would also be possible if the company decided for some reason not to recycle product J.

Optional feedback can be considered in the Gozinto-graph by introducing an additional node J for the second product (in the example: scrap metal). This node is then connected with an arrow to the final product, and a negative weight is assigned to this arrow to indicate that product J is not an input of the production process, but that it instead emerges from the production of product F. The node of product J is then connected to the raw material that can be replaced if J is recycled (R_1 in our example). It is easy to see that the way J is linked to F and R_1 to J ensures that recycling reduces the material requirement of raw material R_1. The weight of the arrow from R_1 to J can finally be interpreted as the recycling rate of the second product in question (90% in our example). Figure 3 shows the updated Gozinto-graph for our example with optional feedback. The updated Gozinto-graph can now be decomposed with the method introduced in Section 3. Tables 3 and 4 show the Gozinto-list and the calculation table for the updated Gozinto-graph with optional feedback, respectively. As can be seen, recycling item J can reduce the secondary demand of item R_1 by 900 units in the example.

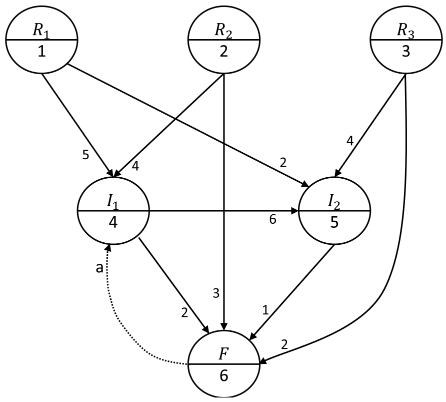
4.1.2 Obligatory feedback

As was described above, in the case of obligatory feedback, it is not possible to produce if the higher-level product is not used at the lower level of the production process. In the Gozinto-graph, obligatory feedback leads to an arrow in the opposite direction of the 'regular' flow of materials, as is illustrated in Figure 4. The problem in this case is that applying the Gozinto-list-method introduced above to such a Gozinto-graph would lead to a loop in the method, as product F would always be required to produce product I_1 and vice versa. As a result, the method would not terminate.

To make it possible to apply the Gozinto-list-method to Gozinto-graphs with obligatory feedback, it is necessary to remove the loop from the Gozinto-graph in a first step. This can be done by differentiating between the net and gross demand of the final product and by introducing an additional node for the net demand into the graph. The net demand then measures the number of items of product F that leave the production process (this equals 1, as the Gozinto-graph is normalised to one unit of output of each node), whereas the gross demand equals the net demand in addition to the units of the final product that are consumed during the production process. In the example presented in Figure 4, the number of units of the final product consumed during the production process can be determined as follows: For each unit of the final product produced, $2a$

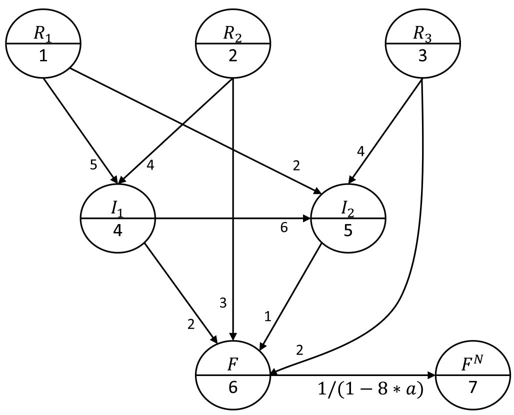
units of the final product need to be produced to satisfy the direct requirement of component I_1. In addition, $6a$ units are needed to satisfy the direct requirement of component I_2 (which requires I_1 and thus, indirectly, F as well). Thus, if one unit of product F is produced, $(2 + 6)a$ units of product F are consumed during production. The net output of the production process would then be $1 - (2 + 6)a$ units of F. To arrive at 1 unit net output, a total of $1/(1 - (2 + 6)a)$ units of F would have to be produced.

Figure 4 Gozinto-graph with obligatory feedback



We can now use this information to remove the loop from the Gozinto-graph. First, the (dashed) arrow in the opposite direction of the regular flow of materials is removed from the graph. Subsequently, we introduce an additional node we refer to as F^N – the net demand – and add an arrow from the original F-node (which is now the gross demand) to this node. The weight of this arrow would in our example be $1/(1 - (2 + 6)a) = 1/(1 - 8a)$. The Gozinto-list-method introduced above may now be used to calculate the secondary demand.

Figure 5 Gozinto-graph with separated net and gross demand for the item subject to feedback



4.2 Time planning with the Gozinto-list-method

One drawback of the Gozinto-list-method introduced above is that it calculates total material requirements, and that the periods when the respective materials are required do not become apparent from this method. However, if some additional assumptions are introduced and if the Gozinto-list-method is slightly modified, it is possible to calculate the timing of requirements as well.

In the original version of the Gozinto-list-method, the Gozinto-graph was decomposed stepwise by eliminating arrows from the graph. In the calculation tables used above, the direct demand of items with a valence of zero $(V_k^i = 0)$ was calculated step by step, and arrows were removed (and valences reduced) whenever a direct demand had been calculated. We now modify the Gozinto-list-method and orient ourselves at the time periods where an item is required for calculating direct demands, and not at the valences. Assuming in the following that each production step consumes exactly one time period, the modified Gozinto-list-method works as follows:

a We define period T as the period where the primary demand occurs. Starting from this period, i.e. from period $t = T$, we calculate direct demands for the periods $t - 1$, $t - 2$, etc. until all valences of all items are zero.

b For products required in period t, we calculate direct demands for period $t - 1$. Calculating direct demands for products with valences of zero reduces the valences of the input material. Calculating direct demands for products with positive valences, in turn, does not lead to a reduction in the valences of the input material.

c The nomenclature used in the calculation tables changes. V_i^t now refers to the valence of product i in period t, and N_i^t is the secondary demand of product i in period t.

d We add additional rows to the calculation table in which we summarise the secondary demand in each period. This helps us to maintain an overview of the secondary demand in each period. In addition, these rows are the starting point for the calculation of the secondary demand in the subsequent period if a further step in the Gozinto-list-method is necessary.

The modified Gozinto-list-method is illustrated in the following. Table 5 presents the results for the example introduced above. In period T, a primary demand of products 5 and 6 occurs. To produce the primary demand, we require items 1 to 5 in period $T - 1$. Note that only for product 6, the valence is zero in period T, and therefore only for products that are required to produce this primary demand, the valences are reduced in period $T - 1$. For the direct demand of product 5, the valences are not reduced (in other words: this arrow is not removed from the Gozinto-graph, as it is required again for calculating the secondary demand of period $T - 2$). We continue this way until we reach period $T - 3$ where all valences are zero. It is not surprising that the total secondary demand is identical to the results of the original Gozinto-list-method where the timing of requirements was not considered. Note that the Gozinto-list-method can easily be extended to the case where some production steps require integer multiples of a basic period.

Table 5 Results for the case where the timing of requirements is considered in the Gozinto-list-method

i	*Primary demand in period T*		*Secondary demand in period T-1*				*Summary: Secondary demand in period T – 1*	
			Item 6		*Item 5*			
	V_i^T	N_i^T	$V_{i,1}$	$N_{i,1}$	$V_{i,2}$	$N_{i,2}$	V_i^{T-1}	N_i^{T-1}
1	2	0	2	0	2	200	2	0 + 200 = 200
2	2	0	1	600	1	0	1	600 + 0 = 600
3	2	0	1	400	1	400	1	400 + 400 = 800
4	2	0	1	400	1	600	1	400 + 600 = 1,000
5	1	*100*	0	200	0		0	200 + 0 = 200
6	-	*200*						

i	*Secondary demand in period T-1*		*Secondary demand in period T-2*				*Summary: Secondary demand in period T – 2*	
			Item 5		*Item 4*			
	V_i^{T-1}	N_i^{T-1}	$V_{i,3}$	$N_{i,3}$	$V_{i,4}$	$N_{i,4}$	V_i^{T-2}	N_i^{T-2}
1	2	200	1	200 * 2 = 400	1	1,000 * 5 = 5,000	1	400 + 5,000 = 5,400
2	1	600	1	200 * 0 = 0	1	1,000 * 4 = 4,000	1	0 + 4,000 = 4,000
3	1	800	0	200 * 4 = 800	0	0	0	800 + 0 = 800
4	1	*1,000*	0	200 * 6 = 1,200	0	0	0	1,200 + 0 = 1,200
5	0	*200*						
6	0	0						

i	*Secondary demand in period T – 2*		*Sec. dem. in period T – 3*		*Summary: Secondary demand in period T – 3*		*Summary: Secondary demand of all items* (= $N_i^T + N_i^{T-1} + N_i^{T-2} + N_i^{T-3}$)
			Item 4				
	V_i^{T-2}	N_i^{T-2}	$V_{i,5}$	$N_{i,5}$	V_i^{T-3}	N_i^{T-3}	
1	1	5,400	0	1,200 * 5 = 6,000	0	6,000	0 + 200 + 5,400 + 6,000 = 11,600
2	1	4,000	0	1,200 * 4 = 4,800	0	4,800	0 + 600 + 4,000 + 4,800 = 9,400
3	0	800	0	1,200 * 0 = 0	0	0	0 + 800 + 800 + 0 = 1,600
4	0	1,200	0		0	0	0 + 1,000 + 1,200 + 0 = 2,200
5	0	0					100 + 200 + 0 + 0 = 300
6	0	0					200 + 0 + 0 + 0 = 200

5 Summary

POM textbooks usually discuss several methods for material requirements planning. Forecasting methods, for example, support the decision maker in predicting future demand by analysing past demand information. Order quantity models are another example of such methods, which determine the optimal ordering policy for given demand scenarios. Especially for high-value products, decomposing BoM is essential for obtaining a precise calculation of material requirements and for avoiding excess stock or shortages. However, exact methods for calculating material requirements have received only little attention in the literature. Although MRP and ERP systems use BoM to determine material requirements, their complexity makes it difficult to discuss them in detail in class, especially in introductory POM courses.

This paper introduced a simple and easy-to-understand method for decomposing BoM. For a given primary demand and a given product structure, the procedure described in this paper can be used to calculate material requirements exactly. As compared to forecasting methods, for example, a precise calculation of material requirements can help to avoid excess inventory or costs associated with stockouts. The basic Gozinto-list-method can easily calculate material requirements for the case where no feedback occurs and where the timing of requirements is not of importance. For scenarios where the product structure is more complex or where the timing of requirements has to be considered in addition, the basic Gozinto-list-method can easily be modified.

The past teaching experience of the authors has shown that the Gozinto-list-method is well suited to raise students' awareness for the role that the structure of a product plays in calculating material requirements and for the advantages an exact calculation of material requirements offers. In addition, the Gozinto-list-method turned out to be a good starting point for the explanation of more complex ERP systems and the way these systems calculate material requirements.

One drawback of the method suggested here clearly is that BoM are required, which are used as input data for the Gozinto-list-method. In practice, information on the structure of products is not always available, especially in cases where products are new or very complex. In this case, an effort to collect the required information and to convert it into the required format has to be made first.

There are several possible directions for extending the method discussed in this paper. For example, the Gozinto-list method assumes that all demands are deterministic. This assumption could be relaxed in an extension by assuming that input-output-relationships are uncertain or fuzzy. Another potential extension could be to include quality issues into the model by assuming that the production process at the different production stages is imperfect producing defective items We leave these and other extensions for future research.

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