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Applications of the Graph Theory in Labour Organization and Rate Fixing of Directly Productive Workers in the Building Sector

This paper presents an improved method for drawing up graph-nets

An important share in our national economy is carried by the building-assembly sector, both from the point of view of the value of work performed and of the man-power involved. Following this situation, any insuficiently used resource might result in important losses. In order to ensure a most efficient use of these resources, an instrument of perception and analysis is necessary which could offer the possibility of establishing the "sore" points on which one has to act. Such an instrument may be considered the theory of graphs, mostly represented by the critical path method. Its utilization in the organization and co-ordination of the building-assembly operations well known generally, and its application yielded positive results. There are, however, some gaps in the manner of approaching the building-assembly questions with the help of the graph theory, which derive from the very methodology of its application:

— There is no scientific procedure of determining the time-limits; the time-limits set for various operations are appreciated either by turning to account an experience previously acquired or on basis of empiric methods conducive to a bigger or lesser degree of arbitraries. For this reason, situations emerge when the volume of work calculated on basis of the time-limits and of the amount of work to be performed do not correspond to the aggregate time appropriated to the work teams during the respective period.

— The present methodology ignores the determining of an optimum constant working staff and, hence, the diminishing of fluctuations.

— Neglecting of ensuring continuity of work at certain specialized teams, as for instance: fitters of various specialities, mosaic and parquet layers, etc.

For tracing down and spotlighting these aspects, an improved variant of the working out and analysis of the graph-nets is proposed, which consists in the following:

1. After drawing a graph-network in the classical form, that would represent the technological links between different activities (operations), without mentioning the time-limits, *a second graph is drawn, with the operations grouped on trades, which contribute to their execution.*

2. *The working out of a computation table* which will include the following data: serial number of the operation performed by a certain trade; the nodes which define the involved operation; the trade participating in the respective operation; the unit of measures and the amount to be performed; the unitary fixed rate of work; the volume of fixed man-hour work; the average index of rate of work fulfilled per involved operation; the volume of effective manhours.

3. *The drawing of a graph-network according to the "time levels"*, bearing in mind the graph-network drawn previously on the basis of which the volume of effective work per operations and trades has been computed.

4. Proceeding from a certain time-limit envisaged previously for the performing of the whole work, a new type of Gantt graph is being worked out, with the observance of the time levels and with all the previously computed work levels written down. We specify that the time proposed initially is usually envisaged in each rough draft and is to be used as starting point in the computation concerning the organization of the building sites. On the basis of the Gantt graph the preponderant trade is selected and the optimum constant working staff is computed; on the basis of this staff, the duration of each time level in part is determined, and the necessary staffs for the other trades are calculated.

5. *The working out of a histogram per trade* for the spotlighting and analysis of the total strength of personnel within each staff in part.

6. The study of the possibilities of matching the histograms with a view of achieving optimum constant working staffs and dropping as much as possible the execution time of the whole work.

1. DRAWING A PER TRADE GRAPH

We shall not insist on the drawing of a graph-network in its classical form, as we consider this thing being well known from the multiple surveys published in specialty literature.

The working out of the second graph with the operations grouped according to trades does not raise, also, any particular problems, except that recommended is to make up a previous list-inventory of the trades involved in each operation in part, and the detailing of the initial graph with arcs corresponding to each trade in part. In other words, the per trade graph will contain in most of cases more arcs than the initial graph, bearing in mind that a certain operation is often performed with the active participation of workers belonging to several trades. Consequently, a more detailed graph will be obtained of the technological links, so that to each arc should correspond a given operation, performed by a given trade. Worth mentioning is the fact that it would be possible for one single operation to appear several times, yet in each case with another trade being assigned to it (Fig. 1).

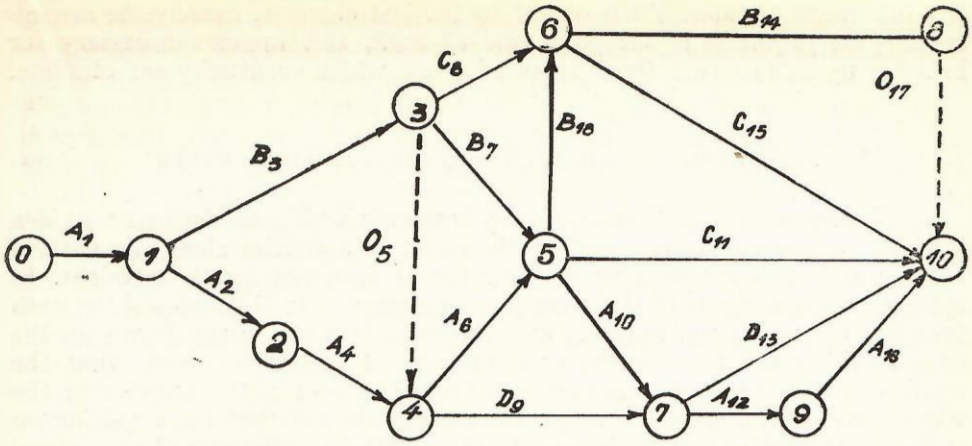


Fig. 1

2. DETERMINING THE VOLUME OF WORK PER TRADE

The drawing of the computation table is aimed at the creation of an as real as possible basis for determining the time needed for the execution of operations, of the whole work, and of the total strength of the working staffs.

Activities (operation per trade)	Nodes of the operation	Trade	Amounts to be performed	Unit of measure	Fixed work rate per amount unit	Volume of fixed man-hour work column 3 × column 5	Average index of fulfilment of fixed work per operation	Volume of effective man-hours column 6 : column 7
1	0—1	A	163	sq.m.	1.46	238	1.27	187
2	1—2	A	140	cu.m.	11.00	1.538	1.27	1,210
3	1—3	B	630	kg	0.10	63	1.20	52
4	2—4	A	566	sq.m.	0.75	425	1.22	348
5	3—4	—	sham activity					
6	4—5	A	3,500	kg	0.10	350	1.20	291
7	3—5	B	56	cu.m.	3.84	216	1.22	177
8	3—6	C	566	sq.m.	0.33	186	1.22	152
9	4—7	D	360	kg	0.10	36	1.28	28
10	5—7	A	70	sq.m.	0.75	53	1.28	41
11	5—10	C	50	cu.m.	3.84	190	1.28	150
12	7—9	A	23	l.m.	2.29	53	1.28	41
13	7—10	D	155	sq.m.	3.52	545	1.27	429
14	6—8	B	164	sq.m.	6.05	990	1.31	756
15	6—10	C	1,750	sq.m.	0.25	438	1.18	371
16	9—10	A	1,573	sq.m.	1.74	2,740	1.30	2,109
17	8—10	—	sham activity					
18	5—6	B	46	sq.m.	1.54	71	1.18	60

The use of this table is aimed at the elimination of the empiric methods of fixing the time needed for the carrying out of various activities and their substitution by methods based on data correctly calculated, as for instance: the amounts to be performed, the fixed work rates and the average index of

the fulfilment of rates. With regard to the last element, namely *the average index of the fulfilment of the fixed rate of work*, this appears necessary for bringing up to date such fixed rates of work which eventually are obsolete.

3. DRAWING THE GRAPH NETWORK PER "TIME LEVELS"

We understand by time-levels the segments which are formed within a a graph, asymetrically oriented, by the effective activities along the path of maximum length supplied by the number of arcs, not by their weight. In other words, the limits of the time levels correspond to the nodes of the path totalling the maximum number, and through these nodes are drawn up the lines marking the time levels. Consequently, it stands to reason that the number of time levels is to be smaller or equal to n—1 of the number of the whole graph's nodes, at the most. It is being noticed that for acquiring an ever more suggestive graphic image, the sham activities (the arcs of zero value) are set out on the vertical, i.e. they superpose upon the line which mark the limits of the time levels.

The drawing of the graph network per time levels must be preceded by the computation of the critical path within the graph drawn up per trade; the arcs of the latter balance the amount of work computed in the previous

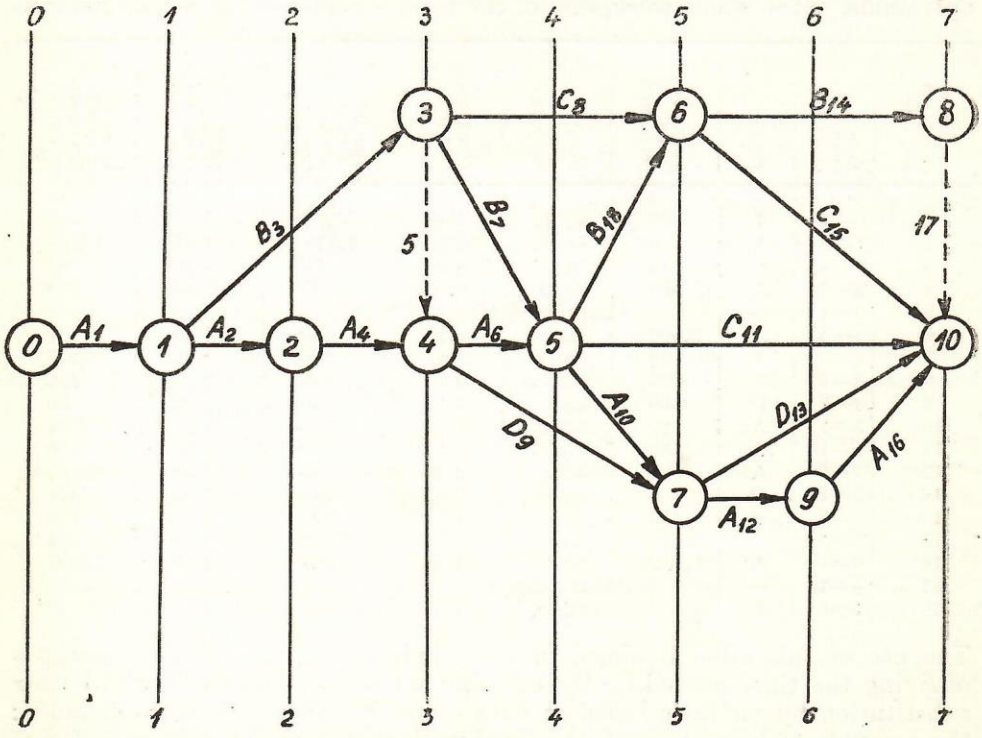


Fig. 2

table. Thus, a first appreciation can be made on the trade which is to be considered as preponderant within the whole work and which generally totals the maximum volume of work. Bearing in mind that the critical path is computed on basis of the volume of work (and not of the time-limits) it is extremely probable that the critical path does not represent the activity of the preponderant trade. Otherwise, either one turns over to another trade (which should be considered preponderant), or to the association of two or three trades. Still, in this case too, one of the two or three trades which figure along the whole critical path of the entire work will carry higher weight, and will be, consequently, appreciated as being preponderant.

It emerges thus that the graph drawn on time limits will have to take into account particularly a certain trade that will be characteristic for the majority of time levels (Fig. 2).

4. DRAWING A NEW TYPE OF GANTT GRAPH

On basis of the graph drawn on time levels, whose arcs weighted the volume of work corresponding to each trade, a Gantt graph is being worked out on time levels and performances. Yet, instead of the classical strips, rectangles will be used, enclosed in the time levels transposed to the Gantt graph. The symbol of the trade as well as the volume of work pertinent to the respective trade and operation will be inscribed in these rectangles.

After the drawing of the whole graph a number of operations with the corresponding trades will result, which will cover one single time level, while the other operations will cover two or several time levels. This will enabel the totalling on the vertical of the volumes of work per trade, which actually concords to the intersections of the graph arcs, i.e. with the determination of the flux on parts of graph. At the same time, it will be noted that the volumes of works of the trades and operations covering several time levels can be assigned either proportionally to all the concerned levels or fully spread over a certain time level, which is less burdened by a volume of work, namely whose sum of the intersection of arcs is smaller. This is a first intervention factor enabling the balancing of the volumes of work and creating possibilities for working staffs with a constant strength.

Having at disposal volumes of work computed for each operation and trade, their sums per each time-level and orientation with regard to the trade which is to be appreciated as preponderant within the whole building work, the orientative execution time-limit for the entire building-assembly work is being set. This time-limit is included in each rough draft, wherefrom it can be taken over, and the possibilities of its reduction are to be analyzed. It must be stressed that the analysis of these possibilities may be made by the designer himself, but, by all means it must be made by those who work on the organization of the site.

This time-limit proposed for the whole work is proportioned to the volume of work of the preponderant trade, and the quotient resulted represents the

Time levels		0—1	1—2	2—3	3—4	4—5	5—6	6—7	Total
Effective volume man-hour per operation	1	$A_1 = 187$							
	2		$A_2 = 1.210$						
	3		$B_3 = 52$						
	4			$A_4 = 348$					
	6				$A_6 = 291$				
	7				$B_7 = 177$				
	8				$C_8 = 152$				
	9				$D_9 = 28$				
	10					$A_{10} = 41$			
	11					$C_{11} = 150$			
	12						$A_{12} = 41$		
	13						$D_{13} = 429$		
	14						$B_{14} = 756$		
	15						$C_{15} = 371$		
	16						$A_{16} = 2.109$		
	18					$B_{18} = 60$			

Effective volume man-hours per operation	A	187	1,210	348	291	41	41	2 109	4,227 man-hours
	B		52		177	60	756		1,587 man-hours
	C				152		521		673 man-hours
	D				28		429		457 man-hours
Duration of time levels (hours)		14.4	93.2	26.8	22 4	3.1	3 1	162.0	325 hours
Staff of trade	A	13	13	13	13	13	13	13	
	B		52 : (93.2 + 26.8) ≅ 1		177 : 22.4 ≅ 8 60 : 3.1 ≅ 19		756 : (3.1 + 162) = 756 : (165.1) ≅ 5		
	C				202 : (22.4 + 3.1) = 202 : 25 5≅8 ; 152 : 25.5 ≅ 6		471 : (3.1 + 162) = 471 : 165.1 ≅ 3 ; 521 : 165.1 = 3		
	D				28 : (22.4 + 3.1) = 1		429 : (3.1 + 162) 429 : 165.1 ≅ 3		

Time envisaged : 320 hours
Staff of trade A
Computed : 13.2 workers (4,227 : 320 = 13.2)

Staff of trade A
Effective : 13 workers
Effective time-limit : 4,227 : 13 = 325 hours

Fig. 3

average constant working staff of the respective trade during the whole building process.

The volume of work of the preponderant trade within each level is proportioned to the time-limit of each time level in part and thus the working staffs for the other trades, specific to each level are being obtained. To balance them, we make use of the above mentioned possibility in case the respective operations cover two or several time levels (Fig. 3).

5. DRAWING PER TRADE HISTOGRAMS

These histograms are an auxiliary instrument for analyzing the dynamics of the working staffs of each trade during the whole time-limit of the performance of building-assembly work. The per trade histograms will have the time units, registered on the abscissa while the number of members of each specialized team will be indicated on the ordinate (Fig. 4).

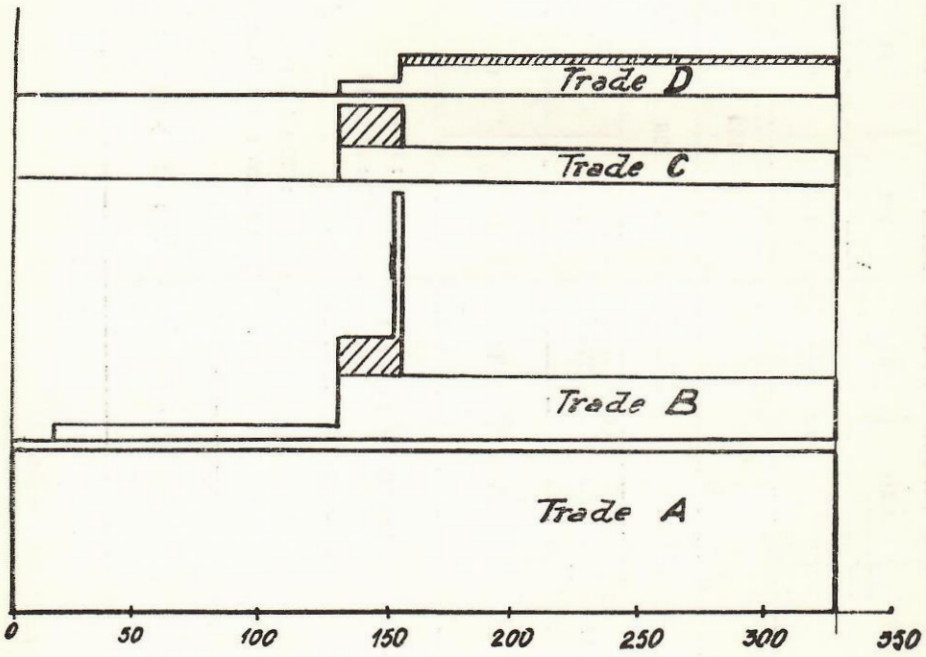


Fig. 4

From the methodology described above, it results more conspicuously that the histogram of the preponderant trade will have a rectangular shape, while for the other trades — the shape of less regular geometrical figures. It is obvious that the attention will be drawn by the vertices of the other histograms, which will be submitted to a thorough analysis with the aim of making them even.

6. ANALYSIS OF HISTOGRAMS AND THE STUDY OF POSSIBILITIES OF THEIR LEVELLING

In this stage, the sector of scientific rate fixing of labour intervenes, which will study the possibilities of levelling the histograms and, consequently the setting up of as constant as possible working staffs. To this end, the possibilities for a temporary transfer of workers to other teams will be studied (hence the necessity of multilateral qualification of the personnel on sites), as well as the intensification of labour during a shorter period, the granting of extra working hours, or, in a last analysis, the lengthening of the whole building process when this does not lead to an important exceeding of the commissioning term.

If these levelling possibilities of the histograms prove insufficient, a new Gantt graph will be drawn, the working staff man-power of the preponderant trade will be changed and, finally, a new trade will be considered preponderant.

REFERENCES

MÜLLER, YVES, *Exercices d'organisation et de recherche opérationnelle*, Eyrolles, Paris, 1965.

LEINEKUGEL, M., *Problemă de repartiţie cu condiţii restrictive*, "Aplicarea metodelor matematice şi mecanizarea evidenţelor în economie". Romanian translation from "Gestion et Informatique" in selective book No. 2,1966 published by the Institute for Technical Documentation, pp. 67—74.

FALKENHAUSEN, HASSO, *Netzplantechnik*, "A.D.L. Nachrichten". No. 30, 33, 34 and 35, 1965.

MULLER-MERBACH, H., *Optimale Losgrössen in der Einkaufs und Fertigungs-Disposition*, "A.D.L. Nachrichten", No. 38 and 40,1966.

APPLICATIONS DE LA THEORIE DES GRAPHES DANS L'ORGANISATION DU TRAVAIL ET LES NORMES CONCERNANT L'EFFECTIF DES OUVRIERS DIRECTEMENT PRODUCTIFS DANS LA CONSTRUCTION

On apprécie que l'utilisation de la théorie des graphes — représentée particulièrement par la méthode du chemin critique — quoiqu'elle mène à des avantages importants dans l'organisation et la planification des travaux de construction et de montage, ne résoud cependant pas les aspects suivants :

1. Corrélation du graphe en réseau avec le volume de travail pour chaque métier séparément et avec les normes de temps respectives.
2. Détermination des équipes qui exécutent les travaux et établissement d'effectifs qui tendent vers des formations de travail constantes, au degré optimum.
3. Garantie de la continuité du travail pour certaines équipes à profil spécialisé telles que : installateurs, installateurs de calorifères, électriciens, etc.

En vue de résoudre les aspects ci-dessus, les auteurs proposent l'application d'une méthode améliorée pour l'élaboration des graphes en réseau.

Les caractéristiques essentielles de la méthode améliorée sont :

a) Elaboration des graphes en réseau par métier et «niveaux de temps» ; on entend par niveaux de temps les segments qui se forment dans le cadre d'un graphe orienté asymmétriquement, ayant des activités effectives le long du chemin de longueur maximum quant au point de vue du nombre des arcs mais non de leur poids.

Les limites des «niveaux de temps» correspondent aux noeuds du chemin comprenant leur nombre maximum ; on précise le fait que les activités fictives (arcs de valeur zéro) ne sont pas prises en considération. On réalise de cette façon une délimitation de portions de graphe (nommées «niveaux de temps») des formations de travail et des possibilités de vérification des réserves de temps.

b) Le poids des arcs représentant le volume de travail (en unités de temps — homme métier) nécessaire à l'exécution d'un travail et non d'une durée globale (ainsi que cela se pratique dans le cadre de la méthode du chemin critique — variante classique — qui laisse dans l'ombre une série de facteurs d'influence difficiles à mettre en évidence).

c) Application parallèle de la méthode du chemin critique et du calcul du rythme maximum dans un graphe, établissant de cette manière la somme des valleurs des arcs (des volumes de travail) pour chaque intersection des graphes, respectivement pour chaque niveau de temps :

— réalisation du travail tout entier dans un temps aussi court que possible ;
— établissement de formations de travail aux effectifs nécessaires et aussi constante que possible ;
— garantie de la continuité de travail pour les équipes de spécialistes.

ПРИМЕНЕНИЕ ТЕОРИИ ГРАФОВ В ОРГАНИЗАЦИИ ТРУДА И НОРМИРОВАНИИ ЧИСЛЕННОГО СОСТАВА ЗАНЯТЫХ НА СТРОИТЕЛЬСТВЕ ОСНОВНЫХ ПРОИЗВОДСТВЕННЫХ РАБОЧИХ

Авторы считают, что применение теории графов, — представленной главным образом методом «критического пути», — несмотря на то, что она приносит значительные выгоды в том, что кассается организации и планирования строительных и монтажных работ, не разрешает, все же, следующие вопросы:

I. Сопоставление сетьевого графа с объемом работы для каждого ремесла (специальности) в отдельности и с соответствующими нормами времени.

2. Определение профиля выполняющих работу бригад и установление такого их численного состава, который приближался бы к составу оптимальной постоянной рабочей бригады.

3. Обеспечение беспрерывности в работе некоторых бригад, обладающих специализированным профилем, как, например: водопроводчики, специалисты по центральному отоплению, электромонтеры и т. д.

Для разрешения вышеприведенных вопросов, авторы рекомендуют применение улучшенного метода разработки сетьевых графов.

В сущности, улучшенный метод характеризуется следующим:

а) Составлением серьевых графов по ремеслам (специальностям) и «уровням времени», причем под «уровнем времени» подразумеваются образующиеся на ассиметрически ориентированном графе отрезки эффективной деятельности, по пути наиболее длинному, с точки зрения числа дуг, а не их удельного веса.

Пределы «уровней времени» соответствуют узлам пути, суммирующему их наибольшее число; подчеркивается, что фиктивная активность (дуги с нулевым значением) не принимаются во внимание. Таким образом, достигается разграничение по частям графа (называемым «уровнем времени») рабочих бригад и возможность проверки запасного времени.

б) Удельным весом дуг, обладающих рабочим объемом (в единицах время человек — ремесло), необходимым для выполнения данной работы, а не общей (суммарной) длительностью (как это практикуется при использовании метода критического пути, — классический вариант, — скрывающего ряд факторов, влияние которых трудно определимо).

в) Параллельным применением метода критического пути и исчисления максимального потока на данном графе, причем, таким образом, эта сумма значений дуг (т. е. обьемов труда) устанавливается на каждом пересечении графов т. е. соответственно, — на каждом уровне времени:

— Осуществлением всей работы за как можно более короткий срок.
— Созданием рабочих бригад с необходимым и как можно более постоянным составом.
— Обеспечением беспрерывности труда специализированных бригад.