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## The nomogram, an artifact changing during the First World War

NATHALIE DAVAL

In the *Encyklopädie der mathematischen Wissenschaften*, the German mathematician Rudolf Mehmke presents in 1902 a classification of mathematical instruments used at that time [3]. Three main types of computational tools are distinguished: numerical tables, graphical tables and mechanical machines. We will focus on nomograms – another name of graphical tables – by studying their role in French artillery during the First World War.

On the front, a simple cannon fire is not insignificant, if only by its cost. Artillerymen need to prepare each shot as well as possible in order for it to be accurate and effective. To make a correct shooting, several important elements must be taken into account: wind speed and direction, variations in air density, weight of projectiles, etc. This preparation requires a significant number of calculations to be achieved within the shortest possible time. At the beginning of the war, the use of numerical tables is frequent, but new artifacts will gradually impose themselves: these are graphical tables made up of graduated lines or points which, by simple graphical reading, make it possible to quickly determine the result of a calculation. The French engineer Maurice d’Ocagne (1862-1938) named these graphical tables “nomograms”, from the Greek *nomos* (law) and *grammè* (traced).

Among the multitude of nomograms used during the war, we can find concurrent-line abaqués. Such a table graphically represents the relationship between three or more variables by means of graduated curves. In his treatise *Nomographie. Les calculs usuels effectués au moyen des abaques* [2], d’Ocagne sets out the general method involved in these abaqués: a given equation  $F(\alpha, \beta, \gamma) = 0$  is considered as the result of the elimination of two auxiliary variables  $x$  and  $y$  from the system of three equations  $F_1(x, y, \alpha) = 0$ ,  $F_2(x, y, \beta) = 0$ , and  $F_3(x, y, \gamma) = 0$ . Then, a solution of the initial equation corresponds to an intersecting point of three curves traced in the Cartesian plane  $Oxy$ .

The book *Carnet de graphiques pour le canon de 75* [1] contains the ballistic elements useful for preparing a shot so that an artilleryman has only simple operations to achieve by using nomograms. The adjustment is carried out according to two main components: direction and inclination. The calculation of these parameters is realized thanks to several nomograms used successively: first, a nomogram permits to calculate the angle wind-firing plan (see Figure 1), which next makes it possible to calculate the transverse wind correction (action on the drift) and the longitudinal wind correction (action on the range). It would also be necessary to study in a similar way the correction of air density, the correction of initial velocity due to powder temperature, the site correction according to the difference in altitude of the cannon and the objective, the correction of convergence in the case of a battery of several cannons, etc.

Later, d’Ocagne realized a major breakthrough in the field of graphical tables by introducing simpler, more readable and complete graphs than the previous ones. The good idea is to replace, by duality, each line by a point so that the concurrence of three lines is transformed into the alignment of three points. Reading is done

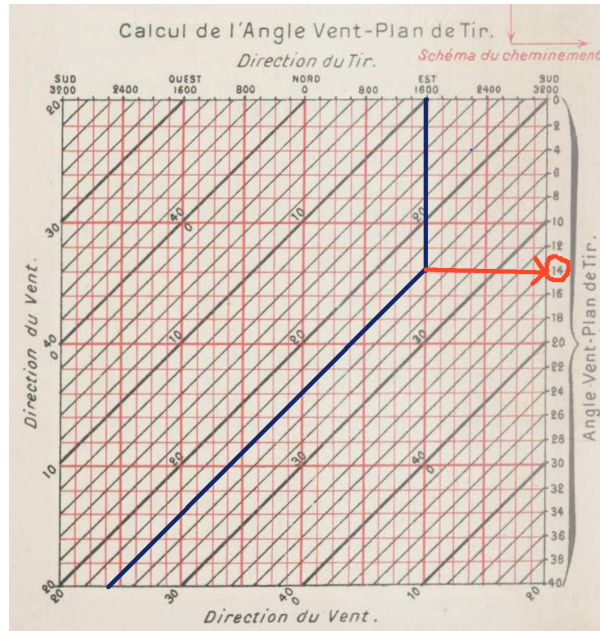


FIGURE 1. Nomogram of the calculation of the angle wind-firing plan ([1], p. 8). Example of use: knowing the direction of the shot (East) and the direction of the wind (24 dagon), we find that the angle wind-firing plan is 14 dagon.

by simple alignment of two values to get the third one. These nomograms are called “alignment nomograms”. For exemple, such a nomogram was used during the war for calculating the firing transport : artillerymen used an auxiliary goal on which batteries of cannons had already fired and then deduced from it the corresponding elements for the final goal. Whilst such calculations would have been long and fastidious in traditional numerical form, the use of an alignment nomogram permitted to achieve them in a few seconds.

D’Ocagne, the “father of nomography”, was an ancient student of the École polytechnique in Paris. He mainly worked as an engineer of the Ponts et Chaussées, notably in the leveling of France. During the War, he became head of a nomographic bureau created for him. But his real passion was mathematics, and more particularly geometry. He became a teacher in astronomy, geodesy and topography at the École nationale des ponts et chaussées and at the École polytechnique. This bivalence sometimes led him to neglect his engineering career in favour of a mathematical one in which he did his best to be recognised through the invention and diffusion of nomography.

At the beginning of the Great War, d’Ocagne helped officers and engineers to build firing nomograms, but he quickly realized that a more complete organisation

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should be set up. In February 1916, Paul Painlevé, Minister of Public Instruction and Inventions concerning National Defense charged him with the development of nomographic work for the needs of artillery and aviation. In January 1917, when the Undersecretariat of State for Inventions is created, a special section of nomography is formed under the direction of d'Ocagne. One of his missions is the establishment of nomograms for many caliber and charges. Very quickly, he receives a lot of letters from the front. According to these letters, there is no doubt about the usefulness of nomograms: they make it possible to significantly shorten the determination of the initial elements of a shot (less than 5 minutes, instead of 15 to 20 minutes before). Many nomograms are then created. D'Ocagne offers training to artillery batteries and is entrusted with young officers wounded at the front to help him. He lists scrupulously the people to whom he sends the precious sesames and in may 1918, the approximate number of sent nomograms of shooting correction amounts to almost 2000 in France and 300 in America.

The craze seems real, but the change of method during the war is not always accepted due to a lack of training and fear of the consequences on shots. The nomographic bureau also receives letters giving the disadvantages of using nomograms. Those that come back frequently are the need of training in order to eliminate any chance of error, the fact that batteries are already trained in other techniques and don't want to change method, and the constatation that the paper seems not to be strong enough and can quickly become dirty and damaged. The aim of the bureau is also to find the most relevant solutions possible for these disadvantages.

Finally, d'Ocagne also received multiple letters of thanks for his method and in 1922, he was elected at the French Académie des sciences at the age of 60: his work at the nomographic bureau had certainly contributed to this election.

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