CALCULATION AND USE OF EFFECTIVE EXTERNAL BOUNDARY AND RELATED SETTING PARAMETERS IN CABLE YARDING PRODUCTION ESTIMATION

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ABSTRACT.—The concept of the effective external boundary has modified traditional methodologies used in the economic evaluation of cable settings. Environmental and safety concerns are strongly influencing silvicultural prescriptions and setting layout in the Pacific Northwest. The ability of the forest engineer to accurately evaluate economic consequences of non-traditional harvesting prescriptions and setting layouts is greatly enhanced when appropriate attention is given to design parameters such as effective external boundary and average external yarding distance. These parameters and others are easily obtained and used within the context of computer-assisted layout design. Two examples based on the literature illustrate the application.

INTRODUCTION

In the not-too-distant past, cable settings in the Pacific Northwest (PNW) were laid out by forest engineers within a well-defined slowly changing operational environment. Despite occasional difficulties with specific settings, logging operators generally felt very comfortable in the conduct of their operations. Indeed it was often said that anyone could make money logging old-growth timber. Clearly times and conditions have changed.

Second-growth timber, very competitive bidding for logging contracts, high regional labor costs, shorter contract execution times, silvicultural practices that emphasize high quality residual stands, stronger environmental safeguards and stricter enforcement of safety regulations are some of the factors that have driven the marginal logger out of business and forced those that remain to take a careful look at their operations.

The picture is not entirely negative - especially for innovative operators. A technological edge exists for those who are willing and able to exploit it. One realization of this technological edge comes in the more efficient use of existing capital and labor resources.

Efficiency in timber harvesting starts with the design of the production facility, which at one stage might consist of laying out the individual setting to take maximum advantage of the available logging equipment and crews. Determining each landing location and placing boundaries for the setting are essential elements in this process. In order to accomplish this task the forest engineer must be familiar with the harvesting systems that are available if only to determine what is feasible and what is not based on mechanical analyses.

Mechanical feasibility is the primary, and often the only criterion applied to cable setting design. Scant attention has been explicitly given to harvesting economics in the PNW since little was needed in its restrictive mountainous terrain where typical logging practice was to clearcut and high-lead yard all merchantable timber. This general indifference to the economics of timber harvesting during the last century has been punctuated by an occasional impulse of interest when the economic viability of the industry was seriously threatened as, for example, it was during the Great Depression. Today the immediate threat is not to the industry as a whole but to the small, independent operator trying to successfully compete within the contemporary economic milieu. In the longer term however the economic health of the forest products industry in the PNW will depend not only on the competitive advantage it enjoys in timber growing but also its relative economic advantage in cutting, processing and transporting logs from woods to market. Whether the forest engineer works for the timberland owner or the

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contract logger it is to the economic advantage of both parties to identify and employ the most cost-effective means of timber harvest and transport.

One purpose of this paper is to encourage forest engineering practitioners and associated analysts to more aggressively employ economic decision criteria in cable setting design. In this regard modern computing technology facilitates the use of several new analytical concepts that can be effectively used to describe some important characteristics of cable settings. The application of these concepts to the economic analysis of cable settings will be demonstrated using examples taken from the literature.

HIGH-LEAD VERSUS SHOTGUN YARDING

Many of the high-lead yarder/towers commonly encountered in the PNW can be rigged as something other than a high-lead cable configuration. For example it is not uncommon to find a logging show where the logger will configure his equipment as either a high-lead or shotgun system depending on yarding conditions (McGonagill 1978). In the example presented here, the relative advantages of these two alternative cable configurations will be compared. Two descriptive measures of the setting, average external yarding distance (AEYD) and average yarding slope (AYS), will be used in making this comparison. In order to effectively illustrate and manipulate these two parameters a convenient archetypical half-tree (yarding through 180 degrees) cable setting is conceptualized as illustrated in Figures 1 and 2. All other setting parameters will be specified and held constant throughout this analysis although it is understood that these also might be varied and their impact on alternative cable configurations compared.

For more realistic illustrative purposes, the published results from two exceptionally well-done cable time studies will be used. The cycle time equation for high-lead yarding is taken from Tennas et al. (1955) and the shotgun cycle time equation is based on one developed by Gibson (1975). Interested readers are referred to these two publications for specific details regarding the equations. It is worth emphasizing that these two cycle time equations were developed for very different machines and crews, not to mention a multitude of other distinctly different factors of operational significance, so that no comparative conclusions can be definitively drawn from the results now to be presented **- only a suggested process of analysis and system comparison is being outlined in this paper**.

The high-lead yarding cycle time equation of Tennas et al. is used without modification in obtaining the results that follow. The cycle time equation, of the form $y=\exp[f(x_1,x_2,,,)]$, given by Gibson for shotgun yarding was approximated with a power series expansion discarding all terms of second order and greater. A very close approximation to Gibson's original equation was observed over the domain of interest.

For the high-lead system the cable road width (average distance from one tailhold block to the next) was set at 75 feet with an average time per road change of 12 minutes. For the skyline system the average road width was set at 150 feet with an average road change time of 64.2 minutes. Delay was estimated as 14% of scheduled operating time for both cable configurations and assumed equally applicable when either yarding or changing roads. The fixed move-in/move-out time was set at 720 minutes and assumed to be done out-of-shift. No delay factor was applied to this fixed time element and it was added to the scheduled operating time of each system before making the final time per unit of output calculation.

Other fixed parameters for this comparison were: 150 logs per acre, 300 board feet per log, 3.3 logs per turn, and 2 choker setters (there is also a rigging slinger). These parameters were essentially the same for both the high-lead and shotgun systems. By somewhat arbitrarily maintaining a common parameter set for both cable configurations the issue of costing out the systems has been sidestepped, at least for this specific illustrative example. The cost evaluation of each system is quite straight forward, but owner specific, and its insertion here would not serve the primary purpose of the paper.

In order to compare the two cable configurations the external yarding distance and yarding slope of the archetypical half-tree setting are varied. The total volume on the setting and the total time required to log that volume using each system are calculated. Consider the following numerical example. If the external yarding distance is 750 feet and the yarding slope is 20 percent on the setting then the following setting parameters are readily calculated: 500 feet for average yarding distance (AYD), 20 percent for average yarding slope (AYS), 281,250 feet-squared for expected square of the yarding distance (ED2), 400 percent-squared for expected square of the yarding slope (ES2), 10,000 feet-percent for expected product of yarding distance times slope (EDS), 2310 feet for the effective external boundary (EEB), and 19.50 acres for the setting area. With these parameters the expected high-lead cycle time is 5.92 minutes and the shotgun cycle time 7.19 minutes. The average lateral yarding distance (ALD) for the skyline (25 feet) is based on the average road width for that system. The expected number of yarding cycles required over the entire setting may be estimated from the total number of logs on the setting and the average number of logs per turn. The total productive time spent changing cable roads is calculated by multiplying the number of cable roads on the setting (estimated by dividing the EEB by the average road width for the system being examined) by the average time expended per road change. Total productive time spent yarding and changing cable roads is then divided by one minus the ratio delay (0.86). This last calculation yields the total scheduled operating time estimate. The fixed time is added to give the final time estimates for this example: 7248 minutes for the high-lead and 9280 minutes for the skyline system. The final result is presented in time per unit of output: 8.26 minutes per Mbf for the high-lead and 10.57 minutes per Mbf for the skyline. All of these calculations are readily done for a variety of different parameter values using a spreadsheet.

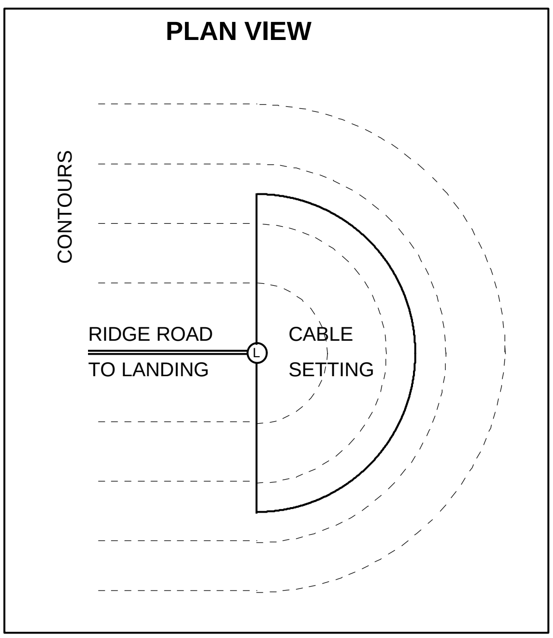

Figure 1.—Aerial view of the setting

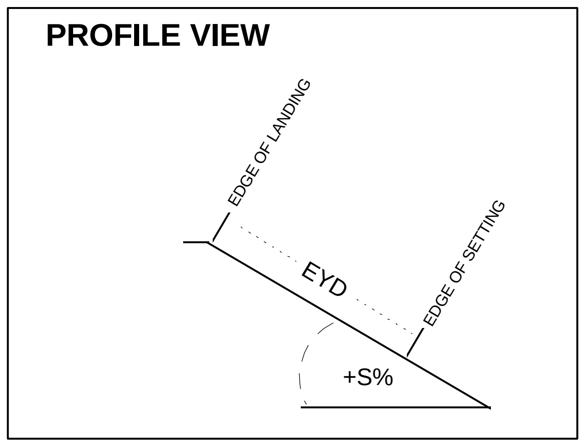

Figure 2.—Cross-sectional view of the setting

The results of such a spreadsheet analysis are shown graphically in Figures 3 and 4. These two figures confirm and perhaps even expand our understanding of cable system performance. It is observed for example that in the case of both systems there is an external yarding distance that will minimize the time per unit of output for a setting with a given yarding slope. This optimal relationship between distance and slope is plotted in Figure 5 as a separate curve for each system. Not unexpectedly, the performance behavior of the two systems with respect to changing slope is fundamentally different. High-lead productivity is adversely affected by increasing slope while shotgun productivity rises with increasing slope - a consequence of its gravity outhaul design. An examination of productivity change with increasing external yarding distance also shows interesting but not unanticipated characteristics of each system. The high-lead system is quite sensitive to yarding distance and shows a well-defined trough in its performance surface. While shotgun system productivity initially shows extreme sensitivity to changes in distance (at short external yarding distances) its performance eventually becomes almost insensitive to changes in distance at the longer external yarding distances - once again a consequence of its gravity outhaul design where at greater distances the continued accelerating force of gravity more than compensates for initially low carriage velocities near the landing.

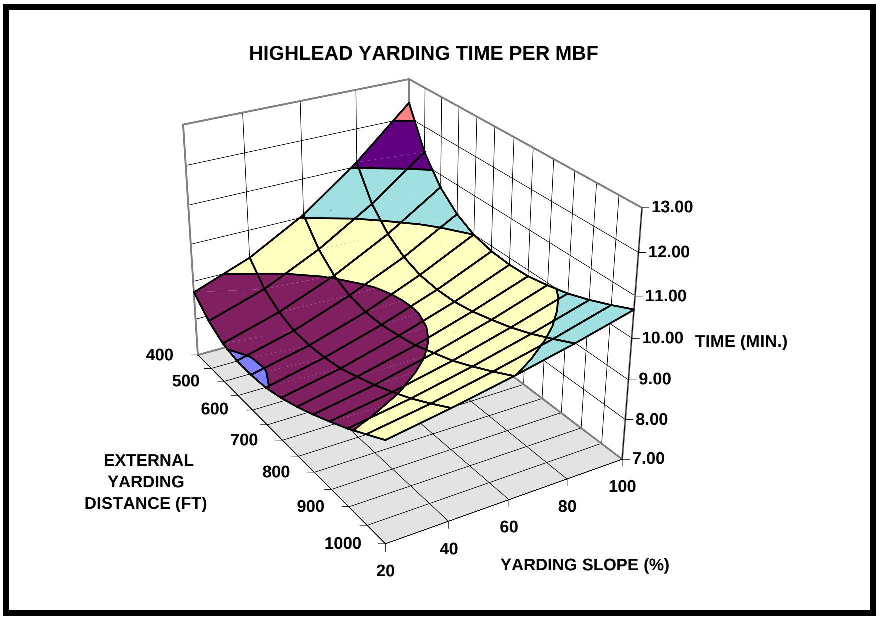

Figure 3.—Performance surface for the high-lead cable configuration

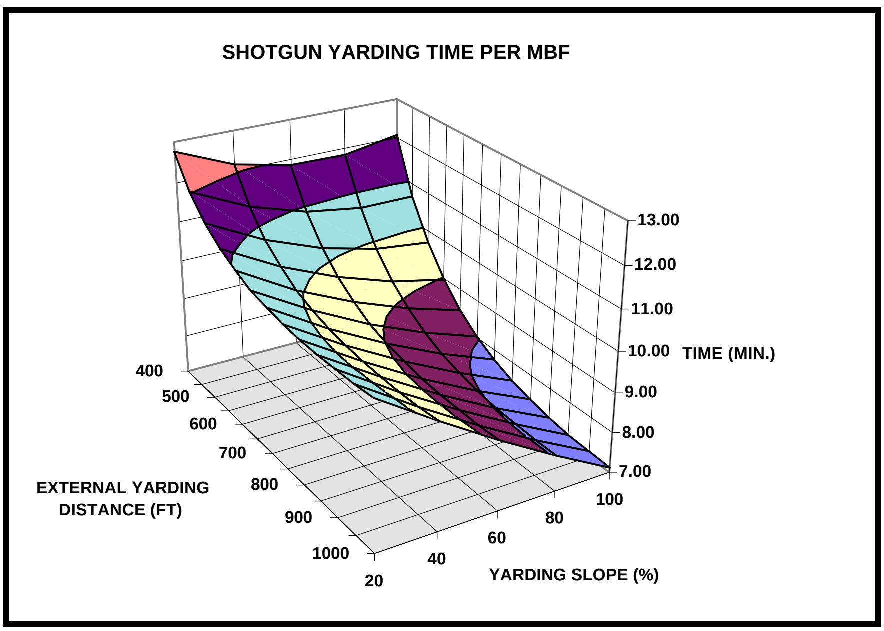

Figure 4.—Performance surface for the shotgun cable configuration

These figures are obviously useful in and of themselves but perhaps of even more interest are the comparisons that they afford between the two systems. One such comparative evaluation can be summarized by examining the space curve formed by the intersection of the two surfaces of Figures 3 and 4. Because of the fundamentally different system responses to increasing slope a very “stable” curve is obtained. A planar projection of this space curve is shown in Figure 5 where it divides the distance-slope domain into two regions - one in which the most productive system is the high-lead and a second where the shotgun is more productive. The “stability” of this curve with respect to its projected location onto the distance-slope plane is due to the angles at which the two performance surfaces intersect; changes in height (performance) of either or both surfaces do not significantly shift the position of the projected curve. Another consequence of these angles is that using the wrong system even within a short distance of the boundary between the two regions will seriously reduce production below what it could be if the correct cable configuration were used. While the reader is once again cautioned regarding specific conclusions based on these two performance surfaces it would certainly appear warranted to conclude that the potential exists to develop curves for individual operations that could be of very substantial practical value to the logger as well as the forest engineer.

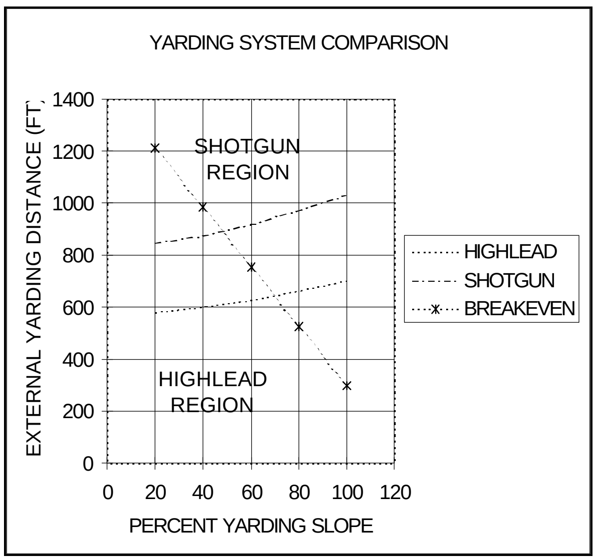

Figure 5.—Yarding system niche by slope and distance

Other archetypical cable settings might be developed that more closely match the typical logging chance of an area. Two obvious possibilities would be half and full-tree settings on a uniform sidehill slope. One advantage of generalized setting models of this type is the ready development of graphs (Fig. 5) or even easily remembered rules of thumb extracted from such graphs; either of which can provide users with a quick indication of what might be the most appropriate yarding equipment for a particular site.

The paper logging plan of the practicing forest engineer is now developed within a data-rich computerized planning environment. There is little reason for the planner to rely solely on rules of thumb in setting design when computer estimates more firmly based on the available data can be easily programmed. The next example shows a higher level of setting design analysis although certainly not the highest currently available. Once again particular attention will be directed toward finding and using setting parameters such as EEB and AEYD which can play key roles in the more accurate calculation of yarding system productivity.

HIGH-LEAD LANDING PLACEMENT EVALUATION

In this example the published results of the time study by Tennas et al. (1955) are once again employed. A hypothetical setting described by Greulich (1992) was selected for evaluation. With the exception of logs per acre which is changed to 200 and volume per log which is now set at 500 board feet the yarding conditions remain the same as in the previous example. The design objective in this case is to examine two alternative landing locations with respect to their relative yarding costs. The shape of this particular setting is irregular and calculation of the EEB and AEYD would be quite tedious without computer assistance. Accordingly a program was written to first identify the external yarding boundary and then subsequently calculate these two setting parameters.

Once the line segments comprising the external yarding boundary have been identified the EEB and AEYD are readily calculated for each component line segment using formulas provided elsewhere (Greulich 1987). The EEB for the entire setting is then quite simply the sum of the EEBs of the individual segments. The AEYD for the setting is calculated as the EEB-weighted grand mean of the segment AEYDs. The two alternative landing locations for this setting were evaluated in this fashion and the calculated setting parameters are shown in Tables 1 and 2. The line segments comprising the external yarding boundary for each landing location are also listed. These boundaries are plotted in Figures 6 and 7 for the two alternative landing locations.

A spreadsheet was then used to evaluate high-lead performance at each of the two alternative landings. The first landing location has a shorter EEB than the second so that only 269 minutes of productive time are expended in cable road changes associated with that landing. The second landing requires 394 minutes of productive time in road changes but that additional time is easily compensated for by its more central location (evidenced by its shorter AYD). In the final analysis the times per unit output are 5.75 and 4.71 minutes/Mbf for the first and second landing locations respectively. The lower yarding cost associated with the second location might ultimately justify its selection but the costs associated with the additional length of access road would also be considered before any choice were made.

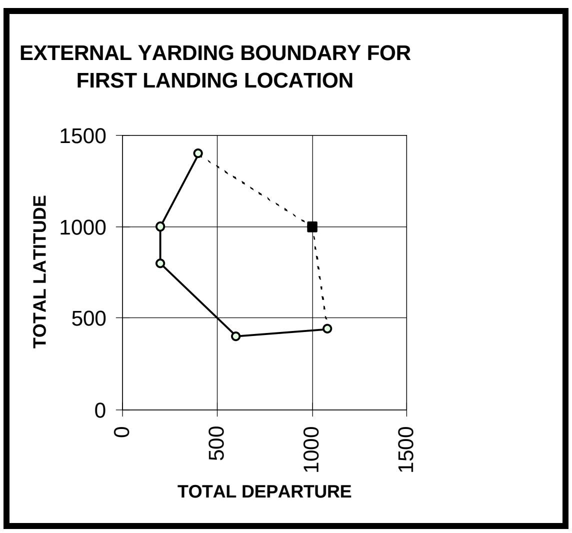

Figure 6.—External yarding boundary, alternative landing location one

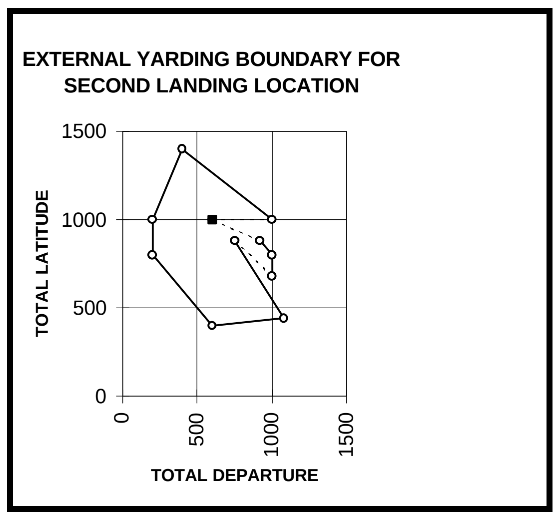

Figure 7.—External yarding boundary, alternative landing location two

CONCLUDING STATEMENT

The external yarding boundary and its measure, the EEB, provide a rational basis for estimating the total number of cable roads required to yard a setting as well as their expected, or average, length (AEYD). Here it has been illustrated how the EEB might be employed to more realistically describe and evaluate cable yarding productivity. The concept and its application were illustrated with two examples. In the first, the EEB was incorporated into a spreadsheet program where yarding productivity of two alternative cable configurations were analyzed for a generic setting layout. The results of this particular analysis strongly suggest that the evaluative procedure is descriptively accurate and that useful numerical results might be easily developed and summarized in graphical form. In the second example a setting with an irregular boundary was evaluated for two alternative high-lead landing locations. A computer program was used to calculate the EEB for subsequent spreadsheet evaluation of yarder productivity. In contrast to the idealized generic setting layout of the first example, site specific conditions are here modeled in considerably more detail. This increased layout detail provides the analyst with the opportunity to more accurately estimate the economic impact of the many irregular designs now being suggested for setting layouts in the PNW.

Table 1.—Computer program output for first landing location

LANDING COORDINATES:		**X_0**	**Y_0**	**Z_0**
		1000.	1000.	1000.
TURNING POINT NUMBER & COORDINATES:	**i**	**X_i**	**Y_i**	**Z_i**
	1	1000.	1000.	1000.
	2	400.	1400.	640.
	3	200.	1000.	840.
	4	200.	800.	780.
	5	320.	920.	840.
	6	360.	1000.	872.
	7	400.	1080.	832.
	8	400.	1000.	880.
	9	400.	920.	856.
	10	320.	920.	840.
	11	200.	800.	780.
	12	600.	400.	740.
	13	1080.	440.	848.
	14	720.	920.	920.
	15	920.	880.	948.
	16	1000.	680.	904.
	17	1000.	800.	940.
	18	920.	880.	948.
	19	720.	920.	920.
	20	600.	800.	860.
	21	400.	800.	820.
	22	600.	1000.	920.
SETTING PARAMETERS:				
TOTAL YARDED AREA OF THE SETTING:	444800.			
AVERAGE YARDING DISTANCE:	557.			
AVERAGE YARDING SLOPE:	33.			
EXPECTED SQUARE OF YARDING DISTANCE:	336253.			
EXPECTED SQUARE OF YARDING SLOPE:	1142.			
EFFECTIVE EXTERNAL BOUNDARY:	1683.			
AVERAGE EXTERNAL YARDING DISTANCE:	750.			
EXTERNAL YARDING BOUNDARY VECTORS:				
	X1,Y1,Z1:	400.	1400.	640.
	X2,Y2,Z2:	200.	1000.	840.
	X1,Y1,Z1:	200.	1000.	840.
	X2,Y2,Z2:	200.	800.	780.
	X1,Y1,Z1:	200.	800.	780.
	X2,Y2,Z2:	600.	400.	740.
	X1,Y1,Z1:	600.	400.	740.
	X2,Y2,Z2:	1080.	440.	848.

Table 2.—Computer program output for second landing location

		X_0	Y_0	Z_0
LANDING COORDINATES:		600.	1000.	920.
SETTING PARAMETERS:				
TOTAL YARDED AREA OF THE SETTING IS:	444800.			
AVERAGE YARDING DISTANCE IS:	347.			
AVERAGE YARDING SLOPE IS:	30.			
EXPECTED SQUARE OF YARDING DISTANCE IS:	141811.			
EXPECTED SQUARE OF YARDING SLOPE IS:	1229.			
EFFECTIVE EXTERNAL BOUNDARY IS:	2461.			
AVERAGE EXTERNAL YARDING DISTANCE IS:	455.			
EXTERNAL YARDING BOUNDARY VECTORS:				
	X1,Y1,Z1:	1000.	1000.	1000.
	X2,Y2,Z2:	400.	1400.	640.
	X1,Y1,Z1:	400.	1400.	640.
	X2,Y2,Z2:	200.	1000.	840.
	X1,Y1,Z1:	200.	1000.	840.
	X2,Y2,Z2:	200.	800.	780.
	X1,Y1,Z1:	200.	800.	780.
	X2,Y2,Z2:	600.	400.	740.
	X1,Y1,Z1:	600.	400.	740.
	X2,Y2,Z2:	1080.	440.	848.
	X1,Y1,Z1:	1080.	440.	848.
	X2,Y2,Z2:	750.	880.	914.
	X1,Y1,Z1:	1000.	680.	904.
	X2,Y2,Z2:	1000.	800.	940.
	X1,Y1,Z1:	1000.	800.	940.
	X2,Y2,Z2:	920.	880.	948.

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