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Computer Layout and Design of Grain Storage Facilities

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INTRODUCTION

A GRAIN storage facility may represent one of the largest single investments made by a farmer. An incorrect design may prove costly because comparable systems often differ in purchase price by several thousand dollars. Another consideration is that the least cost facility relative to initial investment may have the greatest annual expense. Farmers who are about to purchase and/or construct a grain storage facility often seek economic and engineering information from neighbors, builders and equipment dealers. The information they receive is, for the most part, qualitative in nature based on the past experiences of the individuals consulted. The design engineer may be in an excellent position to give sound quantitative information. However, the large number of variables that should be considered when designing a grain facility usually makes comparison of several different systems impractical. To provide a detailed design and cost analysis for several modifications of comparative storage systems usually exceeds the time allotted by engineers or contractors for that purpose. Yet, the producer needs accurate detailed data when making a large and important investment. To meet the needs of the farmer, and to assist the contractor, equipment dealer and engineer in their planning, the computer design simulation BNDZN was developed.

PROGRAM INFORMATION

BNDZN (pronounced "Bin Design") was developed primarily for the design of new facilities using a centralized layout. However, other bin arrangements and older facilities for which expansion is planned may also be evaluated by the program.

The program output may be divided into both design and economic information. Input and output data are arranged so that interested parties can readily examine and compare each design and economic factor related to the system. Alternate plans may be compared by making additional runs of the program. BNDZN allows the designer to concentrate on system concepts rather than mathematical computations and, in effect, convert the specifications of the engineer into a form suitable for his client with a minimum of time and expense.

To put the size and scope of the program into perspective, there are more than 200 inputs related to facility design and approximately 500 economic inputs. Each of these may be specified by the designer, using either a value he chooses or a default value established within the program. The only parameter that must be specified is the design capacity of the

<table>
<thead>
<tr>
<th>Name</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>OURBN</td>
<td>Determines the capacity and dimensions of facilities which have irregularly spaced bins of different sizes.</td>
</tr>
<tr>
<td>YOURBN</td>
<td>Assigns a coordinate location for each bin and determine the lengths of unloading augers.</td>
</tr>
<tr>
<td>LOCATE</td>
<td>Determines the aeration requirements for each bin.</td>
</tr>
<tr>
<td>AERATE</td>
<td>Establishes the equipment requirements for layer drying.</td>
</tr>
<tr>
<td>LAYERD</td>
<td>Establishes the equipment requirements for batch-in-bin drying.</td>
</tr>
<tr>
<td>BATCHD</td>
<td>Establishes the equipment requirements for portable drying.</td>
</tr>
<tr>
<td>WET</td>
<td>Sizes and locates the wet holding bin.</td>
</tr>
<tr>
<td>PORTD</td>
<td>Determines the bucket elevator discharge height for layer drying.</td>
</tr>
<tr>
<td>LAYER</td>
<td>Determines the bucket elevator discharge height for batch-in-bin drying.</td>
</tr>
<tr>
<td>BATCH</td>
<td>Determines the bucket elevator discharge height for portable dryers.</td>
</tr>
<tr>
<td>PORTDR</td>
<td>Specifies the bucket elevator design requirements.</td>
</tr>
<tr>
<td>BUCKET</td>
<td>Calculates the downspouting requirements.</td>
</tr>
<tr>
<td>DOWNSP</td>
<td>Specifies the pit design parameters.</td>
</tr>
<tr>
<td>PIT</td>
<td>Sizes 8-in. U-trough augers.</td>
</tr>
<tr>
<td>PAUGER</td>
<td>Sizes 6-in. tube augers.</td>
</tr>
<tr>
<td>UAUGER</td>
<td>Designs overhead (roof) augers.</td>
</tr>
<tr>
<td>ROFFA</td>
<td>Establishes commercially available electric motors from calculated power requirements.</td>
</tr>
<tr>
<td>ELECMO</td>
<td>Determines a bill of materials, estimates energy consumption, establishes purchase and annual costs.</td>
</tr>
<tr>
<td>ECON</td>
<td>Psychrometric chart routine used in routines involving drying requirements.</td>
</tr>
</tbody>
</table>

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facility. There are 20 subroutines and 4 functions which do the design computations. Table 1 has a listing of these routines and the general purpose of each. The main body of the program reads the specifications of the designer and refers required calculations to the appropriate subroutine or function. These calculations are then returned to the main body where they are formulated into output data.

BASIC LAYOUT CONCEPT

The basic concept used by BNDZN in the location of storage and handling equipment involves the utilization of an X-Y-Z coordinate system (Fig. 1). The center of this coordinate system serves as the reference point for locating bin centers and the charge and discharge points for grain handling equipment. This reference point may be located anywhere on the grid system, but the most convenient location is usually in the middle of the center building. By knowing the X-Y-Z coordinate for all charge and discharge points, one can determine the lengths of augers and downspouting in addition to the discharge height of the bucket elevator. The coordinates also allow easy location of bins and handling equipment when drawing sketches and plans for construction.

The space reserved for the location of the grain facility is divided into six areas plus the section for the center building (Fig. 2). Although there are no fixed dimensions for the areas, their relative locations remain constant. For example, the size and type of facility will regulate the space requirements of Area 1, but BNDZN assumes that Area 1 will always be located in the first quadrant of the coordinate system. The designer specifies the number of bins to be constructed and the area locations for each. Only one storage bin may be assigned to an area, thereby limiting the total number of bins in a single design to six (Fig. 3).

OUTPUT

To illustrate the types of information given by BNDZN, the following discussion will review each of the major output sections to include a brief critique of major input and output design parameters.

Clientele and Designer (Fig. 4)

Preliminary information consists of identifying the individual for whom the facility is designed and the design engineer. This allows quick identification of a program and insures the client that he is getting personalized attention.

Bin Description (Fig. 5)

The initial design information presented by BNDZN states the capacity of the facility based on the parameters specified by the designer. Should the facility have insufficient capacity, owing to other design constraints, a message to that effect will be printed. The stated capacity is based on filling to the bin eave height with no allowance made for compaction.

The “BIN AREA LOCATION” refers to the six areas in which bins may be constructed. The “LOCATION INDEX” specifies in which of the six areas a bin will actually be placed. The “X” and “Y” locations of the bin centers are in reference to the center of the X-Y-Z coordinate system.

The “PERFORATED FLOOR HEIGHT” and the “FOUNDATION RING HEIGHT” are specified by the designer. A height of zero in the data column indicates that the bin will not have that item.

The “BIN DIAMETER,” “BIN EAVE HEIGHT,” “BIN OVERALL HEIGHT,” “BIN CAPACITY,” “ELEVATION OF BIN FOUNDATION,” and “BIN ROOF HEIGHT,” are determined by BNDZN using given data inputs. The “RESERVED LOCATION” refers to an area designated as being reserved for purposes other than the location of a grain bin. An example would be a building located in Areas 1 and 4 such that construction would be restricted to the remaining four areas. The designer has the option of specifying a sweep auger for a bin, from which a “SWEEP AUGER HORSEPOWER” will be determined, and he may also choose to install a grain spreader.

**********************************************************

THIS FACILITY WAS DESIGNED FOR OTTO LOEWER, JR.
LEXINGTON, KY.
606-266-1261

THE DESIGN ENGINEER WAS OTTO J. LOEWER, JR.
AG ENGR DEPT., U OF KENTUCKY
606-258-4955

**********************************************************
Aeration Requirements (Fig. 6)

The design information required for each bin includes the "CFM PER BUSHEL" and "SHEDD'S DATA MULTIPLIER" (used to determine static pressure). From this data and design values calculated previously, each bin includes the "CFM PER BUSHEL" and "SHEDD'S DATA MULTIPLIER" (used to determine static pressure). From this data and design values calculated previously.

### Table: Aeration Requirements

<table>
<thead>
<tr>
<th>Bin Area</th>
<th>Location</th>
<th>Index</th>
<th>CFM Per Bushel</th>
<th>Total CFM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>0.1</td>
<td>733</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>0.1</td>
<td>733</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>0.1</td>
<td>733</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.0</td>
<td>0.1</td>
<td>733</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.0</td>
<td>0.1</td>
<td>733</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1.0</td>
<td>0.1</td>
<td>733</td>
<td></td>
</tr>
</tbody>
</table>

### Table: Drying Technique

<table>
<thead>
<tr>
<th>Bin Area</th>
<th>Location</th>
<th>Index</th>
<th>CFM Per Busel</th>
<th>Total CFM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>0.1</td>
<td>733</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>0.1</td>
<td>733</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>0.1</td>
<td>733</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.0</td>
<td>0.1</td>
<td>733</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.0</td>
<td>0.1</td>
<td>733</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1.0</td>
<td>0.1</td>
<td>733</td>
<td></td>
</tr>
</tbody>
</table>

**FIG. 6 Aeration requirements.**

* A positive value indicates that an item will be constructed, installed, or located. Zero indicates the absence of that item.

**FIG. 7 Drying technique.**

The "TOTAL CFM," "DEPTH OF GRAIN," "STATIC PRESSURE," and "APPROXIMATE HORSEPOWER" are determined. All fan horsepowers calculated in BNDZ are based on the relationship:

Fan Horsepower =

\[
\text{CFM} \times \text{static pressure in inches of water} \times 6356 \times \text{x fan efficiency}
\]

### Table: Bin Description

<table>
<thead>
<tr>
<th>Bin Area</th>
<th>Location</th>
<th>Reserved</th>
<th>Elevation of Bin Centers</th>
<th>Bin Roof Height</th>
<th>Bin Capacity (Bushels)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
<td>0.0</td>
<td>23.8</td>
<td>23.8</td>
<td>6733</td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td>0.0</td>
<td>23.8</td>
<td>23.8</td>
<td>6733</td>
</tr>
<tr>
<td>3</td>
<td>0.0</td>
<td>0.0</td>
<td>23.8</td>
<td>23.8</td>
<td>6733</td>
</tr>
<tr>
<td>4</td>
<td>0.0</td>
<td>0.0</td>
<td>23.8</td>
<td>23.8</td>
<td>6733</td>
</tr>
<tr>
<td>5</td>
<td>0.0</td>
<td>0.0</td>
<td>23.8</td>
<td>23.8</td>
<td>6733</td>
</tr>
<tr>
<td>6</td>
<td>0.0</td>
<td>0.0</td>
<td>23.8</td>
<td>23.8</td>
<td>6733</td>
</tr>
</tbody>
</table>

**FIG. 5 Bin description.**

Following the tabular data for bin descriptions are the assumptions for layout of the facility as given by the designer. This includes data relative to bin sizing, and the location of each bin relative to the reference point of the coordinate system. In addition, the relative location of the center building is stated.

### Aeration Requirements (Fig. 6)

The design information required for each bin includes the "CFM PER BUSHEL" and "SHEDD'S DATA MULTIPLIER" (used to determine static pressure). From this data and design values calculated previously.
**Conditions for the Batch-in-Bin Drying System**: Are that grain will be brought into the bin at 26.0 percent moisture and dried to 13.0 percent. The height of grain in the drying bin will be 4.8 feet, 10.86 cubic feet of air per bushel will be applied to the grain. Outside air temperature and relative humidity will be 60.0 degrees and 65.0 percent respectively. The heated air temperature will be 140.0 degrees and the fan efficiency will be 45.0 percent. Overall dryer efficiency will be 45.0 percent and 75.0 percent respectively.

Under these conditions, 2200.0 bushels may be used to store excess wet grain. The number of bushels for 1, 2, 3, and 4 ft. of depth in the drying bin will be 458.0, 916.1, 1374.1, and 1832.2 respectively. Assuming that 1000.0 bushels can be unloaded per hour, and that 2200.0 bushels of grain are to be removed from the bin, the unloading time will be 2.2 hours. A cooling efficiency of 90.0 percent was assumed.

**FIG. 8 Drying Technique.**

where cfm = total fan output in cubic feet per minute (Loewer et al. 1973).

**Drying Technique (Figs. 7, 8, and 9)**

The basic design inputs for this section include the moisture content of the grain before and after drying and the estimated average temperature and relative humidity during the drying period. The designer may select layer, batch-in-bin, continuous flow or portable batch drying. For any drying method selected, the input data includes drying rates, temperatures, efficiencies, and times. If layer drying is selected, the input data is used to determine the "Drying Rate," "Total Volume Air," "CFM per BU of Undried Grain," "Maximum Static Pressure," "Fan Horsepower," and "Heater Size" (Fig. 7). Batch-in-Bin output data includes fan horsepowers, air output, static pressure, unloading time, cooling time, and heater size information (Fig. 8). The output for portable dryers consists of heater size determination and the sizing and location of the wet holding bin (Fig. 9).

**Pit Requirements (Fig. 10)**

The designer specifies the length, width, and capacity of the pit and whether he wishes to use auger or gravity flow unloading. The structures of both types of pits may be divided into rectangular and triangular sections.

**FIG. 10 Pit requirements.**
The bucket elevator will be charged from the top only. Bucket elevator designs and dimensions vary greatly. However, for use as a guide the following approximations are given for a bucket elevator capacity of 2500 bu. per hour, design parameters included are that there won't be a cleaner attached to the leg (cleaner length = 0 ft.), distribution length will be 4 ft., the discharge height will be 61.1 ft., the leg will extend 7.1 ft. below the ground surface. The drive pulley radius will be 15.0 in., the driven pulley radius will be 10.0 inches, a projection from the belt of 6.5 inches, and a loading efficiency of 90.0 percent.

Using the above criteria for design, the distances between the pulley centers will be 70.3 ft. The height of the leg including the pulleys will be 75.3 ft. and 6 ft. HP. will be required. The bucket elevator will require a 1464 ft. long belt with 203 cups spaced every 0.8 inches, each containing 5.0 pounds of grain. The drive pulley rpm is 43.94 which propels the belt at 345.9 feet per minute or 2.31 rounds per minute. Each complete round of the belt conveys 18 bushels.

** The first stage auger is an 8-in. U-trough.

** A positive value indicates downspouting to the bin located in that area while a zero has the opposite meaning.

** DOWNSPOUTING REQUIRED FOR THIS SYSTEM IS 6.0 INCHES.

** The minimum angles for wet and dry grain were 45.0 and 37.0 degrees.

Economic Considerations (Figs. 16-21)

Each item required for the functioning of the grain facility is placed in one of several categories: BIN, PIT, AUGER ELEVATOR, DRYING TECHNIQUE, MISCELLANEOUS

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** FIG. 12 Bucket elevator requirements.**

** FIG. 13 Downspouting requirements.**

** FIG. 14 Unloading auger requirements.**

** FIG. 15 Roof (overhead) augers.**

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The bucket elevator. Output data specifies the discharge height of the elevator leg above the ground and data relative to horsepower, bucket spacing, belt speed, capacity, and overall height.

Downspouting Requirements (Fig. 13)

From the X-Y-Z coordinates of the top of the bin and the discharge point of the bucket elevator, the required downspouting length to each bin is determined. The designer has the option of downspouting directly to bins located in Areas 5 and 6, or to augers across from bins or supporting structures in Areas 2 and 3. The diameter of the downspouting is calculated from the bucket elevator capacity (McKenzie et al. 1968).

Unloading Auger Requirements (Fig. 14)

The designer specifies the capacity of each unloading auger. Although the bin unloading auger sizes are restricted to 6 in. tubes, a choice must be made between a 6 in. tube and 8 in. U-trough for the diameter of the first stage auger servicing bins in Areas 5 and 6. The designer must also decide whether he wishes sufficient capacity for the first stage auger to allow simultaneous unloading of these bins. From information previously calculated, each unloading auger length, horsepower, and RPM are calculated.

Roof (Overhead) Augers (Fig. 15)

If bins are to be built in Areas 5 and 6, the designer must choose between downspouting directly and augering across from a bin or structure located in Areas 2 or 3. If he decides on the latter, he must select either a 6 in. tube or 8 in. U-trough auger and specify its capacity. From the coordinates of the bin's centers and other input data, auger length, horsepower, and RPM are calculated.
or CONSTRUCTION. The designer assigns each item in each category an expected life to be used in calculating straight line depreciation with no salvage value. In addition, annual cost coefficients for repair, interest, taxes, and insurance are required.

The estimated price for purchasing each item in each category is determined from cost arrays or equations. Each item’s cost was derived from the list price of representative manufacturers with several different manufacturers being used in the overall design. The designer may choose to utilize price multipliers in altering costs. This allows him flexibility in pricing comparable equipment from different manufacturers.

From within the program, the number of base units are determined. For BNDZN, a base unit is defined as a unit for which prices may be estimated or compared. By dividing

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FIG. 16 Bln 2 economic information.

FIG. 17 Pit economic information.

FIG. 18 Bucket elevator economic information.
the expected purchase price by the number of base units, a per unit cost comparison is obtained. To illustrate this concept, BNDZN may determine that the price of a particular bin structure is $3000 with the number of base units for this particular item being 10,000 bu. The per unit base is then 30¢/bu, a typical approach used in comparing bin structures. Similarly, the base units commonly used in comparing augers and motors are linear feet and horsepower, respectively.

**FIG. 19 Drying technique economic information.**

**FIG. 20 Miscellaneous economic information.**

**FIG. 21 Construction economic information.**

**FIG. 22 Electricity.**
The yearly fixed and operating cost for the entire facility is given. In addition, the program. The purchase price for both LP Gas and Natural Gas systems is determined for each of the facilities and those generated by the categories mentioned previously. The cost of electricity is an input, thereby allowing modification of the program to reflect a particular manufacturer or engineer, thus allowing the designer, be he layman or professional, to concentrate on the facility specifications rather than numerical computations. Various layouts and drying techniques may be readily compared with multiple runs of the program. In conclusion, BNDZN represents the application of the “systems approach” to facility design in that the total spectrum of engineering and economic analysis is considered.

For additional information concerning the availability of the program, contact the authors.

**References**