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METHODS FOR REPRESENTING CONDITIONS ON A WEIGHT DATABASE

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Abstract
This paper will look into several conditions that can appear in a weight control project and where all of them need calculation of weight and center of gravity as a variant of the standard lightweight calculation at point of completion. Requirements and wishes for a weight control system to handle these conditions will be discussed and addressed against methods and solutions.

Content

1 Introduction

1.1 Weight Estimation

It is critical to estimate the correct weight and center of gravity to successfully design and build a project with the correct properties. This is perhaps especially true for projects designed to move, float, fly or be launched into space, like vehicles, vessels, platforms, air- or spacecraft, both commercial and military. We will use the term "project" to describe the many types of things for which weight and center of gravity are critical during design and construction.

If the project will carry load, a higher weight than estimated will in most cases result in less loading capacity than anticipated, which can result in reduced payment or, in a worst case scenario, cancellation of the project from the contractor.

A weight increase on a project will also usually increase the building costs, in addition to reducing the load capacity. This is not just due to the design changes a weight increase will impose, but also because weight is a good (perhaps the best) indicator on material quantity and man-hours needed to build the project. Weight is often used as a main parameter for estimating the project's cost, and forms the basis of the quotation from the builder. This means that estimating a weight that is too low can result in a cost overrun and financial loss, while estimating a weight that is too high can lead to being less competitive for the job.

In an early design phase the weight is often estimated based upon parametric scaling or other high level methods, while later in the detailed engineering, weight and center of gravity is often calculated based upon automatic calculation from 3D models in combination with manual calculations of details. During the construction, the weight calculation will include more and more weighed weights as the construction is progressing. But in large projects, the weight database will always include a portion of weight items that are estimated, because it is not practical to get detailed calculations or to weigh all items.

1.2 Weight Control System

To control weights, center of gravity, and other information about the project, a dedicated weight database for the project is good practice.

A weight database, along with a graphical user interface for input, editing, and reporting of data is called a weight control system.

There are various commercial weight control systems for different industries, and some more generic cross-industry ones. Calculation of weight can also be part of an Enterprise Resource Planning (ERP) or Computer Aided Design (CAD) system, but for complex projects these will not be complete. A dedicated system for weight control is therefore usually required; however this system may very well import data from systems like ERP and CAD.

It is also common for companies to develop in-house weight control system. Reasons for this might be specific needs not covered by commercial tools, or legacy systems that were developed prior to the entrance of commercial tools on the market.

1.3 Databases

Most commercial weight control systems uses different forms of relational databases, such as SQL Server, Oracle or MS Access, but older systems can also be found.

The most used in-house tool for weight control is spreadsheet software such as MS Excel, although this is not a proper database and may also lack the structure to be called a system. Still, some people have put a lot of effort into developing spreadsheets to a level of maturity that work quite well, at least until the day the developer of the spreadsheet leaves the company.

1.3.1 Database Structure

In the weight control database the data is often organized to store different categories of weight information in different tables. One reason for this is that different types of information may be relevant for different types of weight items, like bulk weights and equipment weights.

Typically you will find the following information assigned to weight item in a weight database:

- Unique identification of the weight
- Description of the weight item
- User and date information for registration/update of the item
- Weight, center of gravity, quantity, and extension of the item
- Various additional information tagged to the item

1.4 Challenges

The aim of a weight database is to contain the most accurate weight information possible on all items that make up the construction represented in the database. How detailed this information is depends on which phase the project is in. In an early design phase, a weight database may only have a few dozen estimated weights representing areas and/or systems of the project. At the end of construction this may have grown to hundreds of thousands parts in the database.

For reasons to be discussed in the next section, there could be a need to know not only what the final weight of the project will be, but also to be able to tell weight and center of gravity at milestones during construction as well as in future conditions after construction and delivery.

Further, we have the case that a weight item does not necessarily have a constant weight and center of gravity during construction or the lifetime of the item. The weight of an equipment item is often lighter during mounting than at a later stage when fluids and various fittings are added. Some items may also have a temporary position during construction prior to its final mounting. During the life-cycle of a project, items may be added, removed, or change position.

Many projects have moving parts, like drilling towers, cranes, wings, solar panels, etc., which can all change position during operation.

These various conditions make it a challenge to summarize items and calculate the weight and center of gravity for all required situations. **The main goal of this paper is to provide guidance on how to set up a weight database that makes it possible to store, handle, and make summaries for the variety of conditions and situations that are required.**

1.5 Various Conditions Requiring Weight Calculations

1.5.1 Design

In the design phase, various weight and center of gravity estimations are needed. First and foremost, the weight and center of gravity of the project at delivery is needed, but often estimations of weight and center of gravity for various loading conditions and operations are required as well.

1.5.1.1 Loading Conditions

A loading condition is usually defined by variable loads carried by the project, but sometimes items that are a permanent part of the project can change position and/or weight in a particular loading condition. Examples of this are a drill rig that moves around on a fixed platform for oil and gas, a large crane unfolding or turn on a vessel, a wing unfolding on an aircraft, and a solar panel being deployed on a satellite.

1.5.1.2 Concept and Design Evaluation

In an early design phase, several design choices affecting the end result will be made, and an analysis of the consequences related to these various options is needed. Weight and center of gravity for these options are often largely determining the cost, capacity, and other project-crucial parameters for the design, and as such are an important quantity for the decision basis. In the variation of solutions, many weight items will be shared, while others will be relevant only to one or a few of the solutions.

1.5.1.3 Optimization and What-If Analyzes

Especially for projects that move, the combination of weight, center of gravity, and extension for the items must be the best possible to achieve an optimized construction. Different equipment in different positions must be tested and the impact on the total result checked.

As an example, picture the case of designing a vessel to obtain a particular moment of inertia in order to get a favorable rolling period to avoid sea-sickness during operation. By moving large items further away from the global center of gravity, moment of inertia will increase and thus the rolling period will increase.

1.5.1.4 Configurations

In a series production, the design is often modified to get variations of the same base design. This can be changing to newer version of the same equipment to modernize the same design, but it can also be to alter the design to make variations to fit special operations.

1.5.2 Construction

Large projects like oil offshore platforms and large vessels and airplanes will likely be assembled from construction units that are built separately. A lot of lifting and transportation activities follow from this, and weight and center of gravity calculations to support this must be carried out many times during the building of the project.

1.5.2.1 Building Phases

The construction period for larger projects are often divided into different building phases or milestones, and the weight and center of gravity of a construction unit will vary through these phases since they will represent different stages of completion.

In addition to the weight change due to adding more equipment to the unit, temporary weights will also increase through these phases until the point is reached where temporary weights are removed prior to completion. Tools, containers, packaging, and scaffolding are examples of such temporary weights. These weights must be included in the estimation of weight and center of gravity for the phases where such weights exist.

1.5.2.2 Series Production: Evolution and Modifications

In a series production that sustains over time, equipment and parts will often be changed through modifications or replacements during the production time, and a weight database must be able to handle this. This can be relevant for vessels, vehicles, and aircraft production. In addition to this type of production change, type modifications can also be relevant, as described in section 3.5.1.4

1.5.2.3 Cost and Quantities

As mentioned in earlier sections of this paper, weight is an important parameter when estimating the cost of a project. Some building contracts use weights and other quantities as determining factors for calculating the payment milestones of the construction. This means weight is used to determine the quantity of installed material and the work that is associated with this, and therefore weight is used for calculation of the payment to the builder. An example of this is a contract where a shipyard is paid for the constructed steel hull of a vessel using a price per kilo of steel delivered. This means that the weight of the finished steel hull is determining the price directly. But also more complex deliveries, like construction units to an oil platform, the quantity of material delivered is used as basis for payment. This applies to new buildings, but also for modifications contracts. In the case of a modification contract it is very important that the weight database also handles information about the items that are removed, as well as items that are added, since payment is related to the gross weights handled and not the net weight change on the project.

1.5.3 Operation

In the operation phase of a vessel or construction it can be important to know the weight and center of gravity at any point in time. But, for planning of future operations, relevant weight, center of gravity and weight distribution should also be calculated.

Smaller projects like vehicles and airplanes can be weighed on scales to find weight and center of gravity (sometimes combined with a swing pendulum rig to get the vertical center of gravity determined). Inclining experiments and displacement test can be done to find weight and center of gravity on vessels and most floating projects, however for really large floating oil offshore platforms, such tests are not applicable once these projects are operating; therefore an up-to-date weight database of good quality needs to be maintained.

1.5.3.1 Loading Conditions

The number of loading conditions relevant for a vessel is highly variable, and for the most part it will only be the variable load that changes from one condition to the next. But for many vessels, weight and center of gravity for permanent parts of the project change from one condition to the next, as discussed in section 3.5.1.1.

1.5.3.2 Modifications

As written in section 3.5.2.3, modification contracts will often imply payment calculated from weight and quantity changes to the project and not from a fixed price. A contract may specify a price per meter of piping installed to cover both man-hours and material associated with the work. Since the amount of pipe is not known precisely when entering a contract, and design changes will occur at later stages, measuring and keeping account of the quantities delivered forms the basis for payment compensation. These types of contracts are common, for example, on modification works on oil offshore contracts and therefore strict requirements for the quality and reliability of the weight database are imposed.

1.5.3.3 Re-analyze

Projects like vessels and offshore platforms are normally classified to operate for a certain number of years, and strength calculations are carried out according to this expected life. If the lifetime of a project is going to be extended beyond the original intent, a re-classification is needed, which again implies new strength calculations. In these cases it is necessary to have an updated weight database of the project to get correct and approved calculations. The weight database needs to have a level of detail that makes it possible to limit weight and center of gravity to relevant areas and load points on the project. Items that are not needed or cannot be supported by the project due to reduced strength must be considered removed or replaced by newer components in these cases. The weight database must be able to handle different scenarios and perform calculations relevant to the situation for all or parts of the construction.

1.5.3.4 Material Handling

When equipment or parts of the project need to be moved or replaced, weight and center of gravity information is needed to plan lifting and moving. In a weight database, an item may be represented two times in the same weight database. It might be included in a weight for an equipment arrangement that is supported by a common self-supporting skid, but the parts of this arrangement can also be included as isolated items. These items, when summarized, will not make up total weight of the equipment arrangement since they will lack minor components, pipes, fittings, etc., however they are often included since there is a need to know these weights in case of replacements or removal of equipment items. The weight database must handle this situation as well.

1.5.3.5 Weight Change over Time

On maritime constructions, marine growth on hull and structure in contact with the sea increases the weight over time. It is also known that there is a tendency for tools and various equipment to accumulate in spaces and stores. A lot of these items are normally defined as loads, but some of it may be defined as the lightweight of the project, especially if mounted. Other sources of weight which change over time are corrosion and new layers of paint and corrosion protection.

1.5.3.6 Scrapping

When a large project is to be scrapped, completely or partially, it is a challenge to plan the work and also to get enough documentation to price the work. To be able to distinguish between different types of materials is a good help in these cases, since some materials have a high second hand value, while handling other materials may only represent a cost.

1.5.4 Conditions

What is common to all of the situations described in this chapter is that there is a need to perform certain selection of data, including handling different weight and/or center of gravity for the same item, to calculating the correct weight and center of gravity for the situation. For all of the cases above, we will refer to them as **conditions** for the rest of this paper. The structure of the weight database and selection method applied will determine the flexibility, user friendliness, and efficiency of the weight control system, as well as the amount of data to be handled and kept up to date.

1.6 Requirements and Wishes for the Weight Control System

Requirements and wishes for a good and efficient weight control system are plentiful, but in this paper we will focus on the areas related to handling of the various conditions as discussed in the previous chapter.

1.6.1 Avoid Having to Update the Same Data Twice

Even though weight and/or center of gravity for an item will change depending on time and situation, in other words in different conditions, an optimal solution will prescribe that all information that does not change will only need to be defined and updated once. This can be harder to obtain than it may seem, and often a copy of all data is made for each condition needed.

1.6.2 Lessen the Amount of Data

As far as maintaining a good overview, control, and auditability, it is an advantage if the amount of data is as small as possible. To the extent that a large amount of data is required to handle the various conditions and level of details needed, this must be accepted. However, unnecessary data will always reduce system response on editing, calculations, and reporting, as well as increase the likelihood of an error in the database; therefore one should strive to have no more data in the weight database than strictly needed.

1.6.3 Maintain Overview and Simplify Administration of Data

It is important to organize the data in such a way that it is easy to maintain an overview of the information and simplify the administration of the data. The location and storing of data, in terms of how databases, tables, and fields are organized, will to a great extent determine if this will be achieved or not.

1.6.4 Fast Response

When editing, calculating, and reporting weight data, a fast response from the weight database is of course of great importance for an efficient weight control system. The amount of data and the organizing of data, as well as the programming methodology for handling the data is the most important factors for the response.

1.6.5 Flexibility and Scalability

The different types of conditions require different way of sorting and filtering of weight items to calculate the weight and center of gravity that is relevant for the condition. A weight database for a project may need to cope with more than one type of condition, and there will most likely be more than one condition within each type of condition relevant for the project. This calls for a system that has the flexibility to handle different types of conditions, perhaps across different industries.

A weight system where only one field can be used to account for conditions, would be a less flexible weight control system.

1.6.6 Easy Database Administration

The structure of a database can be changed to include new information needed for a specific type of conditions. But in the case of a client application running on top of the database, changes to the database may imply changes to the client application as well, and this is not necessarily a trivial operation. Changes to the database structure will in many cases also involve IT personnel apart from the user. The database ought to be organized in such a way that the weight control system is flexible enough to handle the various conditions without needing changes on the database level, and the setup of the changes can be done by the user.

2 Solutions

Based upon the various conditions where weight and center of gravity calculations are needed (as described in section 3.5) combined with the requirements and wishes for the weight control system (as described in section 3.6), this section will discuss solutions with regards to the organizing of data, but also to filtering and selection.

2.1 Multiple Databases

A kind of "brute force" solution to handle conditions is to have one database for each condition. This may be workable for a project that would require only two or three conditions, but it does not take too much imagination to see that you can easily get in trouble if the number of conditions increases, and the more conditions the worse you will be off with regards to updating of data (same data will be stored many places), and the amount of data (especially if the initial database is large). Maintaining the data will be difficult and you also may end up losing the control of the data.

Figure 1: Multiple Database Configuration

2.2 Single Indicator Field for Conditions

A simple way to handle conditions is to have a single indicator field common for all conditions. This is a simple way to flag whether an item in the database belongs to a particular condition, and this can be combined with data selection to retrieve only data relevant for the condition to be calculated. This is better than using multiple databases since items shared by many conditions only need to be stored once; however, data that is shared by more than one condition cannot be shared (if an item is in more than one condition, it must be in the database multiple times, once for each condition in which it appears) and will face the same disadvantages as for multiple databases in terms of updating, storing, and maintaining of the project.

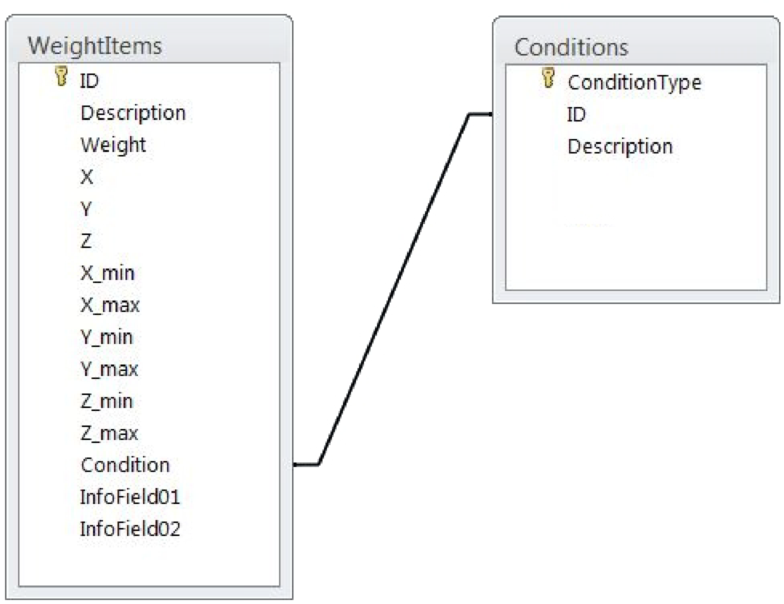


Figure 2: Single Indicator Solution

Sample of condition IDs could be A, B, C, D etc. and to filter for the conditions A, B and D a wildcard [ABD] can be applied.

2.3 Dedicated Indicator Fields for Each Condition

One solution is to have one field in the weight database dedicated for each condition needed and then flag the field corresponding to each condition in which the item is to be included. If the number of conditions is limited, this is a preferred solution by many. The items are only needed once, which reduces problems related to updating and storing to a minimum, and this makes the database relatively easy to maintain. However, it requires a system that is capable of handling the number of fields required for each condition. If the number of conditions gets too large, you will eventually run into problems on the database side for storing and maintaining all the columns.

A series production in which every single product would need to be considered as a condition would represent a case where this method would fail, as you may find yourself needing hundreds of columns.

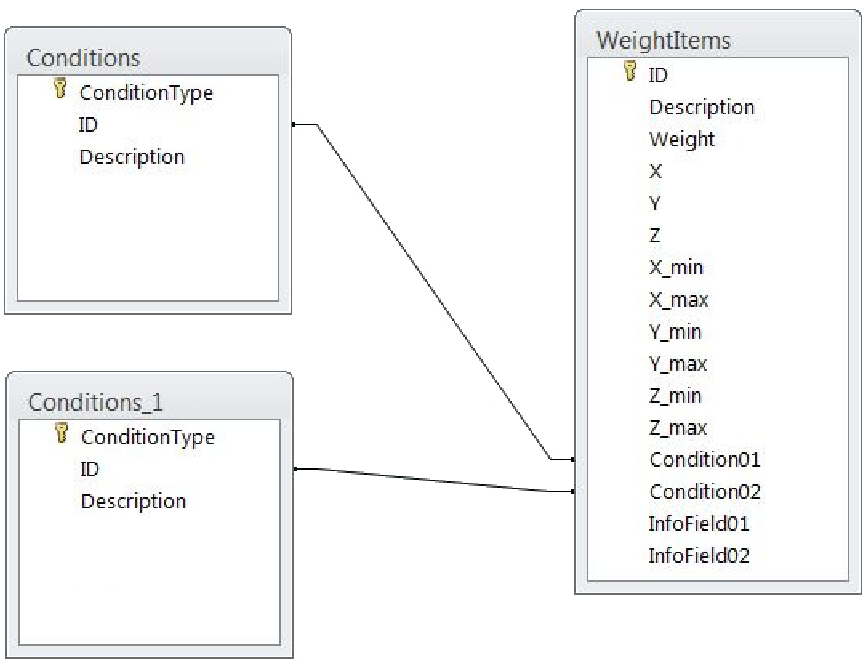


Figure 3: Dedicated Indicator Fields Solution

2.4 Phase Codes

A phase code method is defined as a single indicator field that is combined with a “timeline.” The timeline can represent the building period or a series production.

In the case of the timeline representing the building phase period, the point in time of start (usually set to 0) represents the construction start, and the endpoint in time (usually set to 100) often represents the delivery of the project. Various phases are defined to range from any start-point to endpoint on the time scale, and items tagged to a certain phase means that they are to be included in the calculation of weight and center of gravity throughout the period of time defined for the phase they are tagged to. Items that would be included from the very start until the delivery of the construction would in this case be tagged to a phase that would stretch throughout the whole timescale (in example from 0 to 100, given 0 to be the start and 100 to be time of delivery). Temporary items to be included only in the first part of the building may range from, for example, 10 to 50, while items included only in the last part of the building time may be tagged to a phase defined to range from 30 to 90, in case of temporary items, or from 70 to 100 in case of permanent items.

Code	Time In	Time Out
Phase AD	0	30
Phase CH	20	70
Phase BF	10	50
Phase DJ	30	90
Phase HZ	70	100
Phase AZ	0	100

Figure 4: Example of Phase Code Definition

Using this method for series production, the "timeline" may represent production units (vehicles, vessels, or aircraft), and for a series production of 100 units stretch from 1 (the first unit) until 100 (last unit). Phases would be defined to represent the range of units a particular item would be valid for. Items that are to be included in every unit would be tagged to a phase ranging from 1 to 100. Items that would only be presents in units 20 to 70 would be tagged to a phase that would range from 20 to 70.

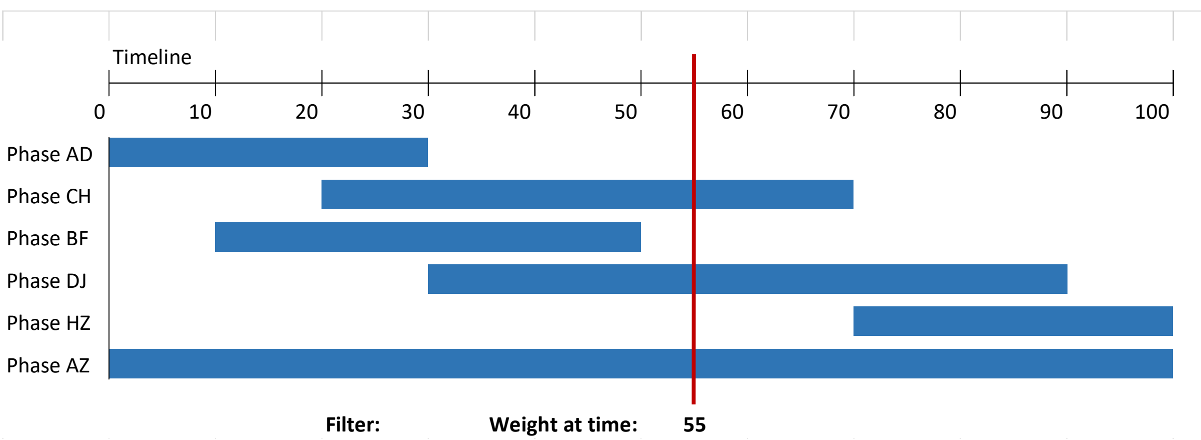


Figure 5: Graphical Representation of the Phase Code Solution

In both cases (building period and series production), the weight and center of gravity for a particular point in time (for a series production this would represent a particular unit) is calculated by adding up all items that are tagged to phases where that particular point in time would be included in the phase's range.

The advantage of this method is that items are only needed once in the database regardless of the number of the phases. It is very easy to deploy the weight items to a range of units or to stretch over a certain period of building time, and it is also a solution that is very scalable in terms of extending the timeline and updating the items.

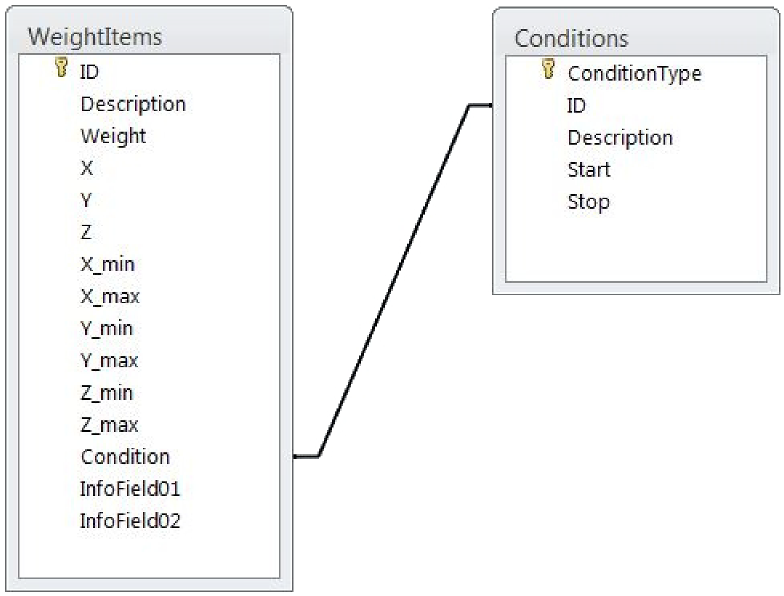
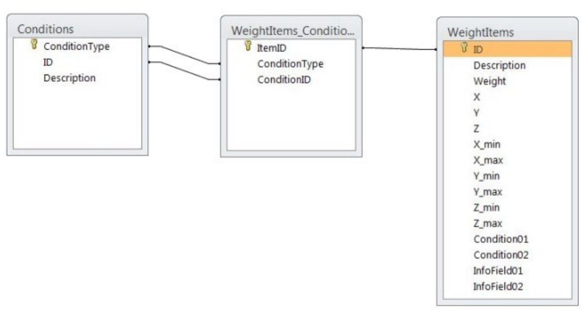


Figure 6: Table Setup for Phase Codes

2.5 Mapping table

As an alternative to flagging conditions for an item directly in the weight table as described in sections 4.2 and 4.3, another approach is to store the relationship between an item and one or more conditions in a separate table. This is illustrated below, where the figure to the left shows a data structure without a mapping table and the use of two fields for conditions, while the figure to the right shows use of a mapping table.



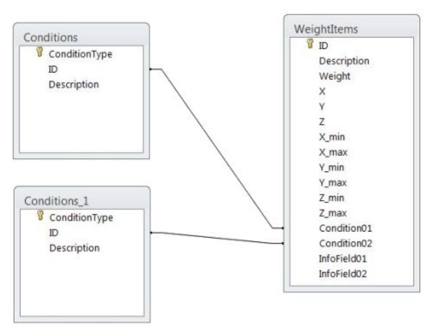


Figure 7: Two Dedicated Fields

Figure 8: Mapping Table Setup

The advantage with this solution is that it is very flexible in terms of how many types of conditions you want to establish. The solution is also good as far as efficient storage (normalized data storing).

The disadvantage is that this solution demands a more complicated user interface to provide a good overview. You cannot simply look up an item in the weight table to check which conditions the item is part of, as is the case with the solutions in sections 4.2 and 4.3.

2.6 Inheritance (Parent – Child)

Another way of handling conditions is through inheritance; that is, to maintain all items that are particular to a specific condition in a separate database similar to a separate project, and then assemble the various parts to build up the complete set of data by referencing the various parts needed in a specific condition.

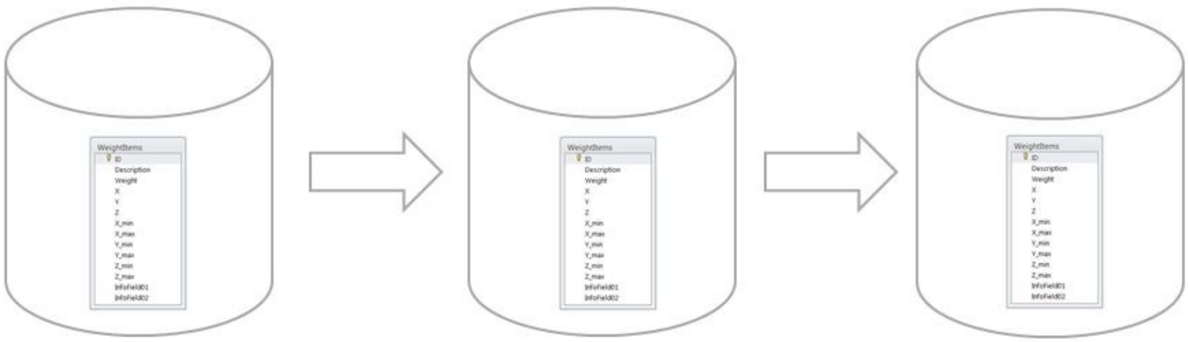


Figure 9: Inheritance Table Setup

In its most simple application this would be represented in a "Parent-Child" relationship, where any "Child" project will "inherit" all data from the "Parent." The end result will then be the combined data from the "Parent" and "Child." A "Parent" can have any number of "Children" and the "Children" will represent items that are specific to the condition the "Child" represents. Of course, more complicated relations can be set up as well.

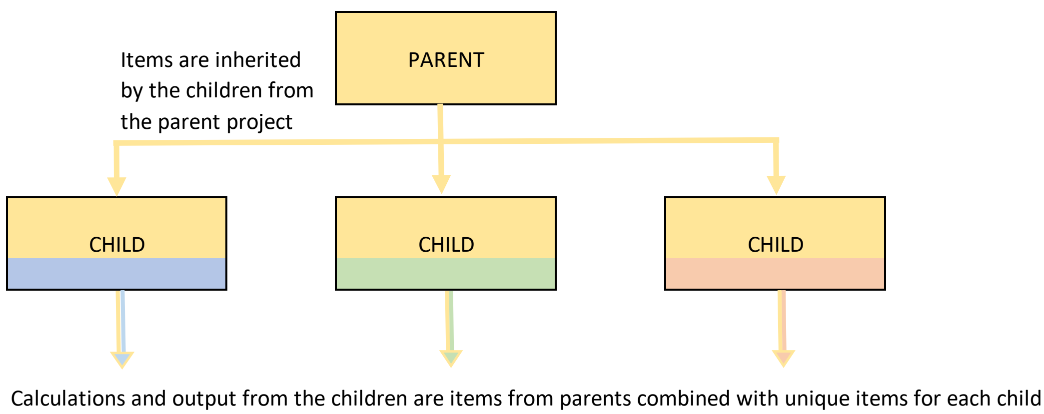


Figure 10: Graphical Display of Parent-Child Method

This method has the advantage of less updating, efficient storage of data, and can in some cases provide a good way to do What-If scenarios and concept evaluation. But, if the relationships become too complicated it may be difficult to maintain a good control of the data.

3 Evaluation of Methods and Solutions

To evaluate which method and solution is best for a particular project, a matrix of conditions and solutions can be set up and points given on a scale from 1 to 6, where 1 represents a poor fit and 6 represents the best fit.

Condition	Multiple Databases	Single Indicator Field	Dedicated Indicator Fields	Phase Codes	Mapping Table	Inheritance
Design						
Concept and Design Evaluation	3	2	5	2	5	4
Optimization and What-If scenarios	1	3	4	3	4	5
Loading Conditions	1	3	4	2	4	3
Configurations	2	4	4	2	5	5
Building						
Building phases	1	4	4	6	5	2
Series productions, evolutions and modifications	2	3	4	5	4	3
Cost and Quantities	1	2	3	5	4	3
Operation						
Loading Conditions	2	3	4	3	4	3
Weight Change Over Time	3	4	4	5	4	3
Materialhandling	4	2	3	5	4	3
Modification	2	3	4	5	4	3
Reanalyzing	2	3	4	5	5	5
Scrapping	2	3	4	5	5	5
Sum	**26**	**39**	**51**	**53**	**57**	**47**

Table 1: Conditions versus Method and Solutions

Similarly, a matrix can be set up of conditions and requirement and again points given on a scale from 1 to 6, where 1 represents a poor fit and 6 represents the best fit.

Requirements and Wishes	Multiple Databases	Single Indicator Field	Dedicated Indicator Fields	Phase Codes	Mapping Table	Inheritance
Avoid Update of Same Data	1	4	4	4	6	4
Lessen the Amount of Data	1	4	4	4	6	4
Maintain Overview and Simple Administration	1	3	4	5	4	5
Fast Response	5	5	5	4	4	3
Flexibility and Scalability	2	3	4	5	5	5
Database administration	2	5	5	5	2	4
Sum	**12**	**24**	**26**	**27**	**27**	**25**

Table 2: Requirement and Wishes against Method and Solutions

4 Conclusion

Weight and center of gravity are critical values in the successful design, bidding, construction, and operation of many different types of projects. Most projects are not just a simple list of items, with their weight and center of gravity; some projects are a series production, with items that are updated during the series run. Others have items that are only included during certain phases of production or operation, or may change locations over time. Yet others have items which deploy and change their center of gravity, or have a different weight during operation than when originally installed. In all of these cases, a proper weight control system is required to deal with the complexity of the situation. Ideally, it would be flexible enough to handle the various situations with the most appropriate approach, to simplify the entry, storage, maintenance, and reporting of the data.

This paper has highlighted some of the methods that can be used to handle various conditions that needs weight and center of gravity calculations, and looked into pros and cons of the methods against various conditions, challenges, requirements and wishes. The chosen solution for an individual project will always be a subjective decisions made from the constraints and properties belonging to the particular project, but from the results in section 3 we can draw the conclusions as a general guidance that multiple databases should be avoided, and that phase codes and mapping table in many cases will come out as the most favorable solution.

Terminology

Term	Definition
Bulk	Component or arrangement of components defined as stock materials or of low complexity. Typically cabling, piping, painting, plating etc.
CAD	Computer Aided Design
Center of gravity	The average location of the weight of an item or construction
CG	Short for center of gravity
CoG	Short for center of gravity
Component	A part of complex categorized either as bulk or equipment
Condition	A state or mode for a construction during building og operation
Construction	A structure such as a building, a vessel, a vehicle or an offshore platform consisting of many components
Equipment	Component or arrangement of components, built for specific function(s). Typically engines, pumps, control cabinets etc.
ERP	Enterprise Resource Planning
Estimate	Determination based on previous experience
Horizontal center of gravity	Center of gravity in the XY-plane
Item	A component
Loading condition	A specific configuration of load on a vehicle or vessel
Vertical center of gravity	Center of gravity in the Z (upward) direction
Weight	A measured heaviness for an item
Weight distribution	The apportioning of weight for a construction along a certain direction (axis) on a certain plane

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