

SIZE RANGES IN MODULAR PRODUCTS - A FINANCIAL APPROACH

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Abstract

This paper presents an approach to using total cost (direct and indirect cost) as a basis for finding the optimal number of module variants or sizes to cover a given requirements distribution and to suggest the performance level of each module variant or size for minimum total cost. Inputs needed are the demand across the entire range of sizes (demanded volume at different performance levels/sizes), the direct (or variable) cost across the range as a function of performance and the indirect (or fixed) cost related to each additional size. The resulting total cost will have a minimum at the optimal number of sizes. Optimal performance level is found by balancing the demand for each size and the direct cost at each size, across the complete range. The resulting proposed performance levels (sizes) are then selected for minimum total direct cost.

The results presented are based on theoretical modelling/calculation, case study experiences and case experiments.

Keywords: Size ranges, modules, integrated cost, design tools, part number reduction

1 Introduction

Most manufacturing companies face varying customer demands. Therefore ranges of products with varying functionality and performance are offered. A product range has often evolved over time as demands have changed and new customer segments have been added. As the range evolves, new sizes are added but rarely are the existing sizes moved or taken out. Due to this lack of constant range evaluation, existing ranges are not likely to be financially optimal.

Existing costing methods, calculating total cost as a function of direct cost, lead to an extensive and increasing number of product sizes. In such calculations, it appears beneficial to meet every single customer's need as accurately as possible and thereby minimizing the direct cost for every particular customer. As each additional size will consume resources in the entire value chain - design, purchase, logistics, production, service and maintenance, etc - a larger number of sizes will also lead to significantly increased indirect cost [1] [2].

It is widely accepted that modularisation facilitates the offering of product ranges in association with requirements for varying performances. Different performance and functionality can be obtained by combining sets of modules to product variants requested by different customers. At the same time the established interfaces between the modules isolates the performance variances to a limited number of modules [3]. This, however, involves

determination of an appropriate number of variants or sizes for each module. In this respect modularisation is closely connected to the establishment of size ranges

The development of size ranges based on similarity laws has been thoroughly dealt with by Pahl and Beitz [4]. The main concern in this work, however, is a technical stepping of product sizes to achieve the same level of material utilization with similar materials if possible, and with the same technology.

The problem of optimising profitability by balancing commonality and variety under uncertain conditions have been explored by Blackenfelt [5], but his approach assumes that the sizes, or rather the performance levels, are given by the market and that the design problem is whether to meet a required size with an optimised design or to over-specify and use a bigger size. We also argue that design decisions should be made on lowest possible level, to minimize the number of parameters affected by the decision. Splitting up the product in modules and making as many design decisions on a modular level helps us understand and model the impact of the decision better than if we try to make decisions on a product level.

This contribution presents a tool, the Size Range Calculator, that balances direct and indirect cost, thereby supporting a design team in the determination of the financial optimal number of performance levels needed for modules that have to come in performance level variants. It also recommends the most profitable performance values for each size.

2 Concept

In order to find the financial (total cost) optimal size range, the following four step course of action is needed:

1. Modelling demand in increased resolution across the range.
2. Modelling direct cost as a function of performances value.
3. Modelling indirect cost as a function of number of performance levels (sizes).
4. Find the financially optimal number of performance levels (sizes) and the cost optimal performance value for each size.

The first step in creating a financial optimal size range is to analyse and model the demand across the range, from the smallest to the largest model. The input to this step will normally be the existing sales or quotation statistics or if available, industry data about sales of different sizes. This statistics will most likely be in terms of volumes for each existing size, and needs to be refined into higher resolution (above what is usual) to tell us more about actual demand at different sizes across the range.

Our experience shows that three different types of demand distribution are enough to enable modelling of the demand. That is, discrete, Gauss distributed and application based demand, Figure 1. Blue bars (grey in greyscale printouts) in the figures below illustrates points of existing demand statistics (revealed demand) and the black bars illustrates high resolution modelled demand (modelled revealed demand):

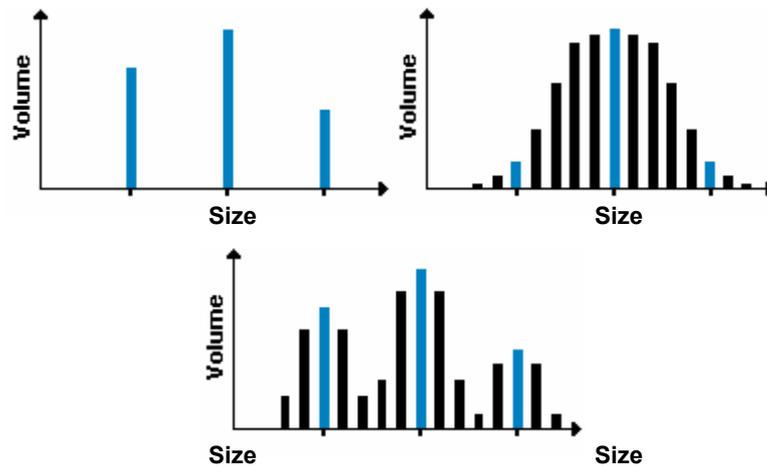


Figure 1. Demand models

A discrete demand is limited to discrete performance levels, normally due to real or de facto standards. An example is ranges of 3-phase motors, with respect to voltage.

Gauss distributed demand is a demand at every performance level, and due to the large size of the market total demand is Gauss distributed. An example is ranges of customized electrical motor and gear units, with respect to power (torque and speed).

Application based demand is a multi-modal distribution, having multiple peaks around different application specific performance levels. An example is ranges of drive units (power electronics) to control a range of electrical motors, where the optimal operation of the motor is likely to create a peak in demand for drive unit power whereas certain customers need to use the motor harder or lighter creates a spread around the optimal performance.

The second step is to analyse and model the direct cost across the range, from the smallest to the largest model. The inputs to this step are the existing price agreements with suppliers (direct material cost) and production and assembly times converted to cost (direct labour cost). The direct cost shall preferably be described as a mathematical function of performance. Our experiences show that most real direct cost situations can be derived from combinations of four different types of direct cost models. Linear, step, progressive and regressive cost functions, Figure 2.

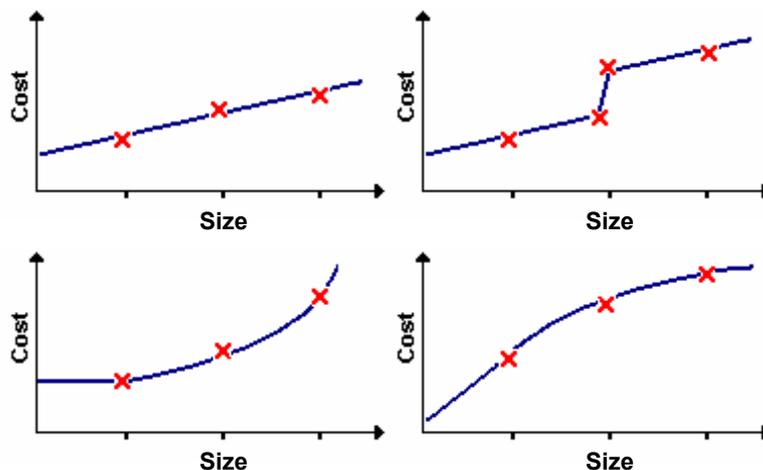


Figure 2. Direct cost functions

Linear direct cost: Cost is a linear function of performance. This seems to be usual case when moving in a limited range and tends to be valid when amount of material is linear to performance and the market is very fragmented with multiple competitors offering different sizes.

Stepping direct cost: Cost is taking steps at discrete performance values. This may be the case when increased performance requires a new technology or process.

Progressive direct cost: Cost is a progressive function of performance. This type of cost function can be the case when the desired performance is subject to larger and larger losses as we increase the performance (desired performance is an output in terms of speed, acceleration, temperature, etc).

Regressive direct cost: Cost is a regressive function of performance. This type of cost function can be the case when doubling the performance requires less than double the material (desired performance is volume of storage tank, stiffness, etc).

The third step is to model the indirect costs. Of course, a larger number of sizes will require more design resources, more tooling, more set-up time, more planning, etc.

Indirect costs may be modelled based on a calculated [6] standard cost per part number. Thus, each size in the range will have to carry a fixed, indirect cost in relation to the additional part numbers caused by that additional size, Figure 3 (the total indirect cost increases as we increase the number of sizes). According to other research and studies, e.g. Zenger and Cafone [7], part number cost varies from US\$ 300 to 15,000 per year depending on the complexity of products and varies with difference in sizes.

More accurate is to perform an investigation of the actual company's indirect cost situation resulting in annual differential cost caused by an additional size in two main processes:

1. Annual depreciated cost for an additional size in the design processes. This is cost to design, verify, set-up production, purchase components, educate personnel, etc related to an additional size.
2. Annual additional cost occurring in the material flow. For example cost to call material, receive material, store material, change over production, store spare parts, etc related to an additional size.

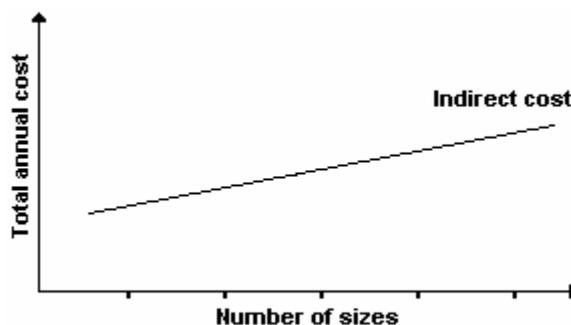


Figure 3. Annual indirect cost

The indirect cost as a function of number of sizes is then approximated as linear.

The fourth step involves finding the financially optimal range, with respect to the direct and indirect cost affected by the range decision. The derivative of the direct cost as a function of performance determined in Step 2 is giving a function describing “over-specification cost”, that is, the direct cost penalty for delivering more performance (a larger size) than the customer actually needs. In this case the derivative of a linear direct cost function and thus also “over-specification cost” are independent of performance value, Figure 4.



Figure 4. The “over-specification cost”

The problem is to find the minimum specific cost as a function of number of performance levels (number of sizes) and of the actual performance values at each size, that is:

‘How many sizes shall we offer and at which performance level shall we locate each sizes to get a minimum cost?’

The answer to the question can be described as a general optimisation problem:

$$\min_{n, \bar{x}} (Cost(n, \bar{x})) \quad (1)$$

where n is the number of steps and \bar{x} the vector of individual performance values

$$\bar{x} = x_1 \dots x_n \quad (2)$$

and the specific cost function is given by

$$Cost = \sum_{k=1}^n \int_{x_{k-1}}^{x_k} \tilde{f}_x(x) \cdot C_d(x_k) dx + C_i \cdot n \quad (3)$$

where $C_d(x_k)$ is the direct cost at performance value x_k and C_i is the indirect cost per size.

The function $\tilde{f}_x(x)$ is a continuous approximation of the underlying true demand curve, which is unknown, but reflected by a discrete demand curve, as indicated in Figure 1.

The “Size Range Calculator”, presented below, is an industrial and practical solution to resolving the multi variable optimisation problem at hand.

3 The Size Range Calculator

In this paragraph the Size Range Calculator tool is explained with the help of an illustrative example for an electric drive system (drive and motor).

The first step is to increase resolution of existing demand statistics (revealed demand), by choosing a type of demand distribution and map this against the existing statistics. This is

done by chopping up each existing size steps into small steps and distributing the existing demand statistics over the new steps according to chosen demand distribution type. In Figure 3 an example of demand for three drive systems – 4500 W sold in 620 units/year, 5000 W sold in 1150 units/year and 6000 W sold in 630 units/year – is modelled according to a application based demand distribution.

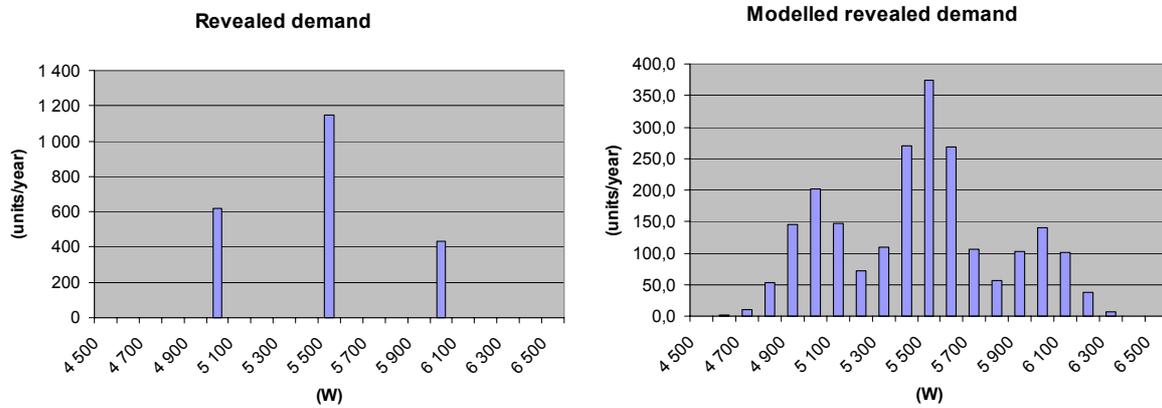


Figure 5. Modelling demand

In the second step, direct cost is modelled as a function of performance. In this case, as in most practical cases we have worked with, direct cost (C_d) is a linear function of performance (x).

$$C_d = 23 + 0,07x \quad (4)$$

This also means that the over-specification cost is constant (independent of performance) as shown in Table 1.

Revealed demand		Modelled revealed demand		Over spec cost (\$/W unit)	Demand corrected over spec cost (\$/W year)	Acc. demand corrected over spec cost (\$/W year)	n=2	n=3	n=4	n=5	n=6
Performance (W)	Demand (units/year)	Performance (W)	Demand (units/year)								
		4 500	0,0	0,07	0,00	0,00					
		4 600	1,0	0,07	0,07	0,07					
		4 700	10,1	0,07	0,70	0,78					
		4 800	53,2	0,07	3,73	4,50					
		4 900	144,7	0,07	10,13	14,63					
5 000	620	5 000	202,0	0,07	14,14	28,77				1	1
		5 100	146,5	0,07	10,26	39,03			1		
		5 200	71,9	0,07	5,03	44,06					
		5 300	108,8	0,07	7,62	51,68		1			
		5 400	269,4	0,07	18,86	70,53	1		2	2	3
5 500	1 150	5 500	374,7	0,07	26,23	96,76		2		3	4
		5 600	269,1	0,07	18,84	115,60			3		
		5 700	105,7	0,07	7,40	123,00				4	
		5 800	55,6	0,07	3,89	126,89					5
		5 900	102,2	0,07	7,15	134,04					
6 000	430	6 000	140,2	0,07	9,81	143,85					
		6 100	100,4	0,07	7,03	150,88					
		6 200	36,9	0,07	2,58	153,46					
		6 300	7,0	0,07	0,49	153,95					
		6 400	0,7	0,07	0,05	154,00					
		6 500	0,0	0,07	0,00	154,00	2	3	4	5	6
	2 200		2 200		154						

Specific cost	Indirect cost	Direct cost
1 004 000	30 000	974 000
989 491	45 000	944 491
981 734	60 000	921 734
990 275	75 000	915 275
1 002 984	90 000	912 984

Table 1. Searching for minimal cost for a range

To get the minimum total direct cost, the tool proposes a minimal total “Demand corrected over-specification cost” based on the assumption that this occurs when each size carries the same amount of “Demand corrected over-specification cost”.

That is, if we want to divide our range into:

2 sizes: $154/2=77$ in “demand corrected over-specification cost” ~5300 and 5500 W

3 sizes: $154/3=51,3$ in “demand corrected...” ~5100, 5400 and 5600 W

Etc as indicated in right part of Table 1.

The third step is to model indirect cost as a function of number of sizes. In this example, indirect cost is US\$ 15000 per size.

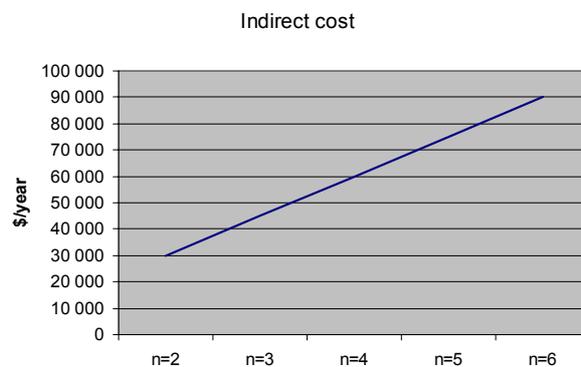


Figure 6. Annual indirect cost as a function of number of sizes

The fourth and final step is finding the cost optimal range. The total annual direct cost as a function of number of sizes is calculated as the direct cost at each chosen performance level times the volume at that size.

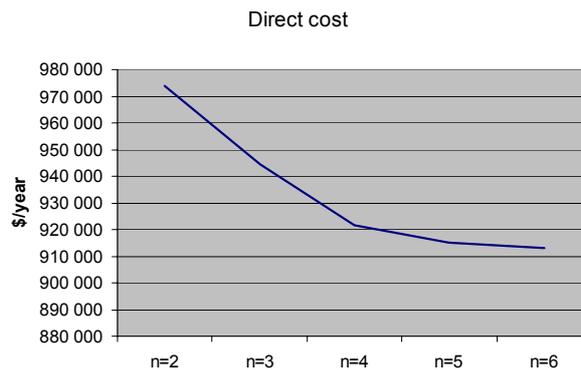


Figure 7. The total annual direct cost as a function of number of sizes

Adding direct and indirect cost gives the specific cost (the cost affected by the range decision) as a function of number of sizes. The specific cost curve normally has a minimum at a certain number of sizes.

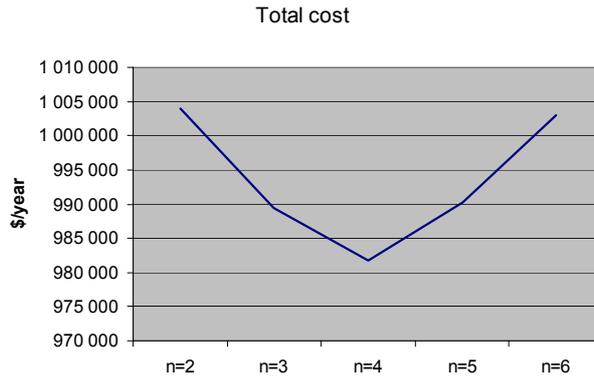


Figure 8. The specific annual cost as a function of number of sizes

The number of sizes and the performance level of each size can now be decided as shown in Table 2.

Result n=4	
Performance (W)	Demand (units/year)
5090	550
5420	550
5600	550
6500	550
	2200
Direct cost	921 085
Indirect cost	60 000
Specific cost	981 085

Table 2. New cost optimised size range

4 Achieved results

The Size Range Calculator has been used in a number of real industrial cases. For confidentiality reasons, no details can be presented.

One recent case was the determination of the size steps of three modules in an HVAC-system (Heating/Ventilation/Air Conditioning). The components modelled were compressor, blower and water heater core. The tool yielded very useful practical discussions, and the team members reached consensus in four hours. The general comment after the session was that this work would have taken much longer without the tool.

In another recent case, the tool was used to decide a range of core drive components in a white goods application. The original intention was to choose the traditionally used sizes. The “Size range calculator” analysis showed in a couple of hours that the traditional approach implied too many sizes and missed the peaks in demand for this specific application. The estimated savings are 200 000 € in indirect cost for skipping two sizes and 75 000 € in direct cost for better precision in meeting the demand distribution across the range. The project leader stated that this type of range decision normally required one week of meetings and workshops ending up with a poorer result.

In an earlier case, the Size Range Calculator was used to determine a range of marine drive lines. The outcome was that the company is decreasing its range of power trains from 12 to 7 sizes, whereof two sizes are new. The estimated annual savings are 350-500 000 €, corresponding to 3-5% decrease of the total product cost (direct and indirect cost).

5 Discussion

Taking indirect cost into account for the design of product ranges, will drive towards fewer sizes and thus free up resources. This is not profitable, unless management moves these resources to new profitable activities or actively decrease indirect cost by laying off people, selling machines, etc. The range re-design therefore needs management support all the way from decision to implementation.

Balancing the requirement distribution and the direct cost across the range also enables minimizing the total direct cost. It is probably obvious that the over-specification cost occurring when diverging from the actual demand hurts more with bigger sales volumes, since the over-specification cost is variable. Still, most companies that we have worked with do not use anticipated volume distribution as a key input to product design. Instead, the old range is used as a template and additional sizes are added if required by the marketing organisation. In these cases, “The size range calculator” has opened many eyes to the importance of designing according to volume distribution.

Modelling the revealed demand curve can be done in a number of ways – either as in the example as Gauss curves or as discussed as discrete demand at certain values or in simpler shapes like rectangles. The choice of model does not seem to affect the ideal number of sizes, but the exact performance value of each size will differ slightly due to selected demand distribution model.

The presented tool only elaborates the optimum costs and does not consider the resulting profit for the company. As such, the tool is recommended when a decrease of the number of sizes is likely to have none or very small effect on sales volume or sales price, which is true for components, modules or sub-systems that are performing low interest side functions (for example the performance of a washer pump for a truck buyer) and for components, modules, sub-systems or entire products that have:

1. “Labelled performance” - customers can only see the specified or labelled performance, not determine actual performance.
2. “Classified performance” - customers are limited by classification to use the product within specified performance limits.
3. “Suppressed performance”- performance is suppressed or limited by software or hardware.

The proposed performance levels are based on:

1. The assumption that to get the minimum total direct cost we shall select the performance levels giving minimal total “Demand corrected over-specification cost”
2. Minimal “demand corrected over-specification cost” occurs when each size carries the same amount of “Demand corrected over-specification cost”.

This assumption has so far never been proven wrong in real case studies.

6 Future work

An incorporation of the search for highest profit will require a model that describes possible losses in sales volume or price level due to a resulting decreased number of sizes. The design of such a model will require further research and studies.

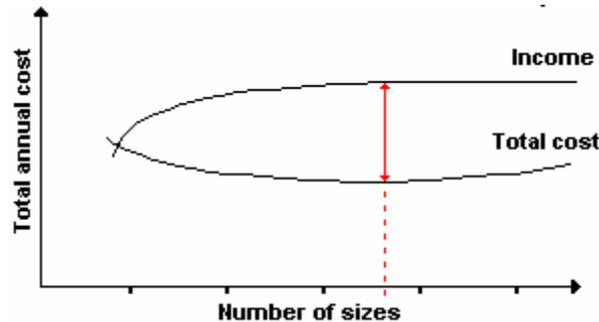


Figure 9. Profit as a function of number of sizes, maximum indicated

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