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Centralized and distributed food manufacture

Almena Ruiz, Alberto; Fryer, Peter; Bakalis, Serafim; Lopez-Quiroga, Estefania

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1   **Centralized and distributed food manufacture: A modelling platform for**

2   **technological, environmental and economic assessment at different production**

3   **scales.**

4   A. Almena[a] , P. J. Fryer[a] , S. Bakalis[b], E. Lopez-Quiroga[a*]

5   [a]School of Chemical Engineering, University of Birmingham, B15 2TT, UK

6   [b]*Faculty of Engineering,* The University of Nottingham, NG7 2RD, UK

7   **Abstract**

8   Centralized manufacturing methods have been increasingly implemented in the food

9   manufacturing sector. Proving to be more cost-efficient in terms of production, centralization

10   also involve rigid and lengthy supply chains with high both environmental and cost impacts.

11   Distributed manufacturing, based on local production at small scale, represents an alternative

12   that could provide flexibility to the currently established centralized supply chains, together

13   with environmental and social benefits. A modelling tool for the process design, evaluation

14   and comparison of different centralized and decentralized manufacturing scenarios, both in

15   economic and environmental terms, is presented in this work. The production of a dried food

16   product (cereal baby porridge) has been chosen as a case study. Three decentralized –(i)

17   Home Manufacturing (HM), (ii) Food Incubator (FI), (iii) Distributed Manufacturing (DM)– and

18   two centralized –(iv) Single Plant (SP) and (v) Multi-plant (MP)– production scales were

19   evaluated for throughput values ranging from 0.5 kg/h to 6000 kg/h, and different operational

20   regions (i.e. unfeasible, transition and plateau) were identified for each scale. A production

21   scenario using UK dry baby food demand was also studied. The most decentralized scales

22   (HM and FI) become profitable (i.e. production cost below market prices) at very low

23   production rates (e.g. 1 kg/h) that industrial manufacturing (showing a lower boundary for SP

24   profitability at 200 kg/h) cannot achieve. HM and FI remain competitive to SP at national

25   demands such as UK dimension – HM has a cost just 1% higher. DM scenarios require low

26   management costs to represent an efficient alternative to SP. Finally, for equal power source,

27   decentralized manufacture does not imply saving in energy or greenhouse gases emissions

28   (GHG) but demand more manpower.

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30   *Corresponding author: e.lopez-quiroga@bham.ac.uk*

33

34   **1. Introduction**

35   At the beginning of the 18th Century, manufacturing was carried out by small facilities

36   located close to consumers. Products were developed using craft methods by artisan

37   manufacturers spread across communities. Their target market was the local neighborhood,

38   and in this way local demand was satisfied (Cipolla, 2003). The Industrial Revolution

39   established a factory system, that combined machinery with sources of power, and gathered

40   a high number of workers under supervision (Schmenner, 2010). The production of goods was

41   relocated into big facilities, achieving rise in productivity and great cost reduction. Such

42   *Centralized Manufacturing*, taking advantage of technology and economies of scale

43   (Helpman, 1981), uses a small number of very large production plants to satisfy the whole

44   demand for a good in a certain country, and possibly overseas demand via exports (Roos et

45   al., 2016). The final product must be standardized as large-scale production requires a

46   standard product for the entire market. Many regional characteristics were therefore lost.

47   These plants can be built far from the market, seeking cheaper labor and taxes. As a

48   consequence of such centralization, the concept of supply chain arises (Fahimnia et al., 2013).

49   The food Industry is the largest industry sector in the UK contributing £113 billion to the

50   economy (DEFRA, 2017). The food supply chain comprises several stages (Tassou et al.,

51   2014): i) production or farming of raw materials ii) transport of raw materials to the processing

52   facility iii) manufacture of the food product iv) distribution from manufacturers to retailers (shop

53   or restaurant) v) retail storage vi) sale. Each stage involves financial cost, energy consumption

54   and environmental impact. The UK food supply chain consumes 367 TWh every year (18% of

55   total energy) and is responsible for 147 Mt CO_2 e. emissions (15% of total associated to UK)

56   (DEFRA, 2017). Transport costs are significant.

57   Thus, a partial return to low scale manufacture situated near customers could be more

58   environmentally acceptable, minimizing transport and storage cost is the up-to-date research

59   in this field. These two attributes, i.e. small scale and location close to customers

60   (*decentralization*), set the basis for *Distributed Manufacturing* (Cottee, 2014). Drivers for this

61   change include new technologies, rising logistics costs, and changing global economies (Matt

62   et al., 2015). Figure 1 schematically shows Centralized and Distributed Manufacturing.

63   At low throughput, fixed costs become too expensive for large plants and this drives the

64   cost above the market price. The advantages of the economies of scale are lost (Ruffo et al.,

65   2015) so an alternative manufacturing system must be found. Such alternative could be

66   Artisan Manufacture. Craft production at small scale can provide fresh and trusted local food,

67   for example following traditional recipes developed by local chefs (Kuznesof et al., 1997).

68   Each local craft manufacturer can introduce variations on the product, resulting in local

69   customization (Rauch, et al, 2016). Locating manufacture close to consumers shortens the

70   supply chain, so energy use related to distribution and storage will decrease (Srai et al, 2016)

71   as well as emissions caused by transportation. Shorter supply chains can also provide fresher

72   and natural products. The brewery sector in the UK can be taken as a good example of this

73   return to artisan/craft manufacture, with a growth of 184% in the number of microbreweries

74   between 2002 and 2013 (Ellis and Bosworth, 2015).

75   Decentralization is a scale-down problem, addressing the loss of economies of scale. There

76   are few studies (Angeles-Martinez et al., 2018) on how these scenarios might unfold. In this

77   work, we proposed a model-based methodology to evaluate and compare the profitability of

78   different food manufacturing scenarios across a wide range of production scales and

79   decentralization alternatives.

80
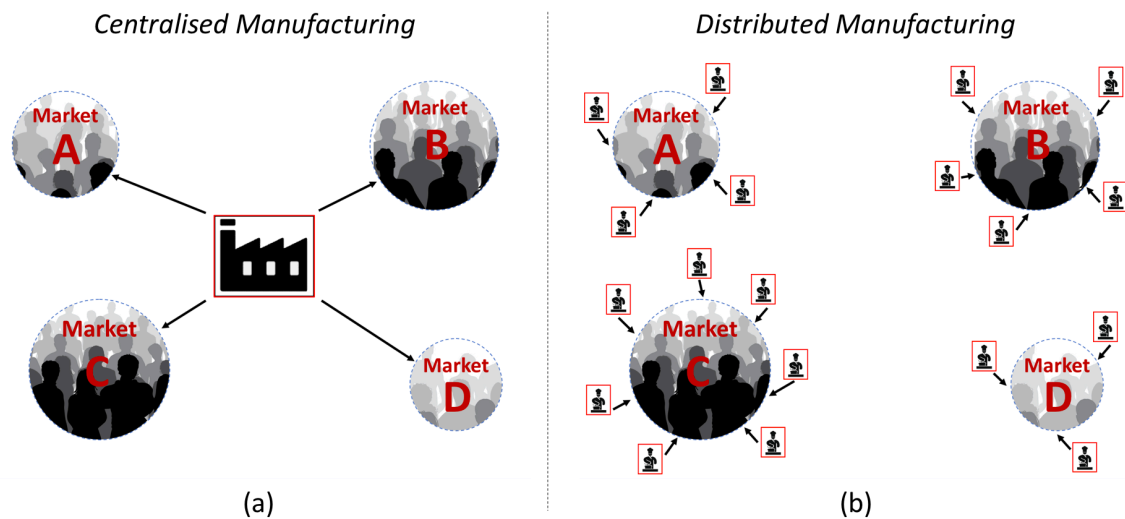
Figure 1: Food product supply chain. (a) Centralized Manufacturing (scenario A) vs. (b) Distributed Manufacturing (scenario B). A net of manufacturing facilities replaces a big plant for supplying the demand of a product in four different markets.

81

82   The basis of this methodology will be illustrated using a dry food product (dry cereal

83   porridge, reconstitutable with the addition of water or milk). The manufacture of dried foods is

84   energy intensive due to the heat loads required to remove all the water in the products (Ladha-

85   Sabur et al., 2019), although transportation and storage is cheap, as no energy is required for

86   preservation and its specific volume is low as they are dehydrated. An efficient result for dry

87   foods would suggest profitability for products that could take more potential advantages from

88   decentralized manufacture methods, such as refrigerated and frozen goods.

89

90   **2.   Characterization of different manufacturing scenarios**

91   2.1. General description of the manufacture process

92   Two different manufacturing methods are considered in this work: industrial and artisanal

93   production. The unfeasibility of industrial Table 1 lists the most representative production

94   conditions and equipment for each case. Industrial production is based on a process line

95   (Figure 2(a)), whilst Artisan production keeps the same unit operations but at smaller scales.

96   This requires changes in the equipment (see Figure 2(b)) and other manufacturing aspects,

97   e.g. batch operation. Further equipment details (e.g. prices, dimensions, capacities) are

98   provided in the Supplementary Material (see Table S.1, Table S.2 and Table S.3).

99   The result of both processes is a final product – reconstitutable dry cereal porridge – with

100   the following composition: 35 w% oat, 11 w% rice, 30 w% milk powder, 20 w% of sugar, 3 w%

101   of palm oil and 1 w% of malt extract, with a final 6% water content.

102

(a)
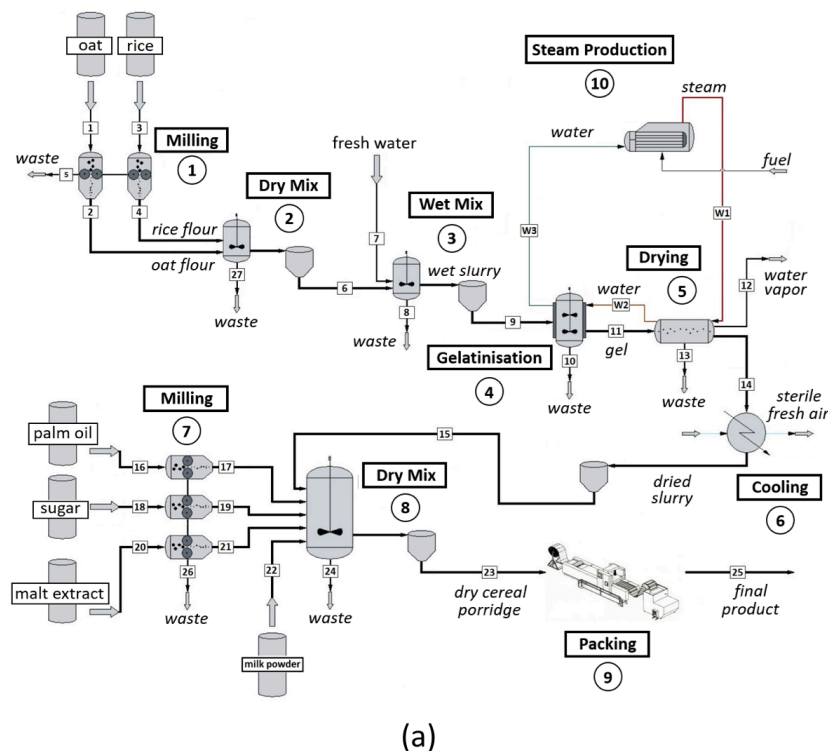
Figure 2(a): Baby food plant production flow chart depicting all the steps of the industrial process. As this is a semi-continuous process, intermediate storage tanks are used to ensure a continuous throughput. Red flow line represents heat integration.
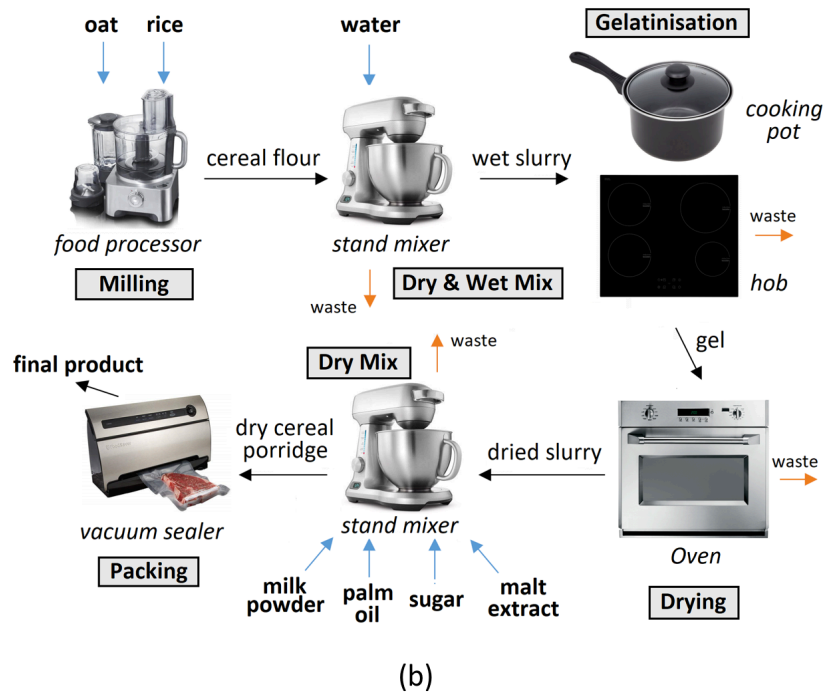
Figure 2(b): Artisanal manufacture flow chart. The industrial unit operations are adapted to be developed as a domestic kitchen batch process.

103

104   2.2. Production scenarios

105   Four different scenarios for the production of dry cereal porridge were considered, from

106   extreme distribution to centralization, as depicted in Figure 3:

107   i) *On-demand economy*: Home Manufacturing (HM). This is based on home production,

108   using the 'gig-economy' model (Stanford, 2017). It is assumed that a group of cooks produce

109   the food at home (1 worker per kitchen) and sell it on-demand.

110   ii) *Sharing economy*: Food incubator (FI). This scenario can be described in terms of

111   owners of under-utilized physical assets renting them to develop an economic activity

112   (Frenken, 2017), e.g. Airbnb®. A Food Incubator can be defined as a group of cooks renting

113   suitable premises and specialized equipment to satisfy a demand.

114

115
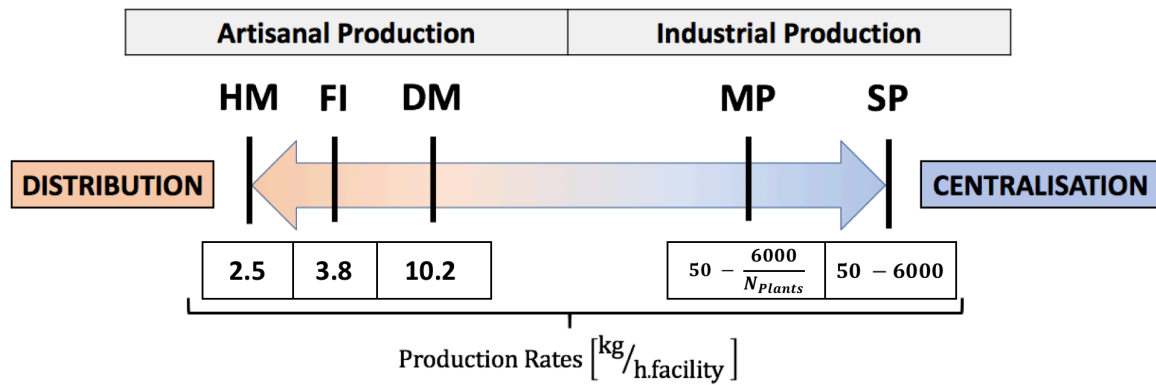
Figure 3: Schematics representing the production methods and scale considered in this work. HM: Home Manufacturing, FI: Food Incubator, DM: Distributed Manufacture, SP: Single Plant, MP: Multiple Plant. The production rate numbers respond to the manufacturing scales designed on this work. N_{Plants} is the chosen number of factories comprising the multi-plant net.

116

117   iii) Distributed Manufacturing (DM). This is also based on the 'artisanal' method and it seeks

118   production rates to compete with the industrial process. It consists of a given number of small

119   facilities/kitchens spread around a community, city or region. The required number of facilities

120   and workers varies according to product throughput.

121   iv) Centralized manufacturing: Single and Multiple Plant Production (SP, MP). The fourth

122   scenario corresponds to a big industrial plant –or a number– designed to satisfy product

123   demand.

124

125   **3. Model description**

126   The model describes the manufacture of dry cereal porridge based on both industrial and

127   artisanal manufacturing flowsheets. This allows the scale-down and comparison of the

128   different scenarios studied at a range of production rates (from 0.5 kg/h up to 6000 kg/h). The

129   whole set of equations includes mass and energy balances - used to design the process unit

130   operations (i.e. drying) and evaluate energy demand - economic analysis and carbon footprint

131   estimation. The viability of each production scenario is assessed using the calculated profits

132 and environmental impacts obtained as model outcomes. Overall, the model consists of 40

133 decision variables, 800 parameters, 2500 equations and has been implemented on Matlab®.

134

135 3.1. Model assumptions.

136 *3.1.1. General assumptions*

137 • The water content of the cereal flour, milk powder, sugar and malt extract considered in

138 the moisture mass balances is 12.0% (The Quaker Oats Company, 1984), 2.5% (Reh

139 et al., 2004), 1.75% (Bitjoka et al., 2007), and 2.0% (Lancaster, 1923) respectively.

140 • The waste for mixing (dry and wet), gelatinization, milling and drying, is taken a value of

141 1% of the unit inflow.

142 • Greenhouse gas emission (GHG) are estimated from calculated energy demand using

143 the corresponding energy conversion factors (Government of the United Kingdom,

144 2017c). These factors estimate the emissions, i.e. environmental impact, associated to

145 different activities such as burning fuels and electricity consumption (see Table S.12 in

146 the Supplementary material for values).

147 • The selling format for is a baby food pouch of 0.2 kg.

148

149 *3.1.2. Industrial production method assumptions*

150 • The time for plant/s annual operation is 16 hours/day for 48 weeks, 5 days a week (2

151 shifts) (Maroulis and Saravacos, 2008), closed for 4 weeks for maintenance.

152 • Equipment size depends on plant throughput. Mass balances provide information of the

153 capacity that each unit must have.

154 • Mills, blenders, stirred tank and storage units are oversized using security factors

155 (Walas, 1990). The chosen unit is the one with the next-higher volume found on the

156   corresponding industrial catalogue: mills (Stedman, 2017), double cone mixer (Tapasya

157   Engineerign Works, 2017) and ribbon blender (Paul O. Abbe, 2017).

158   • Different efficiencies for the boilers and burners are assumed during the operation,

159   depending on the fuel: 72.5% for natural gas, 76.0% of heavy fuel oil and diesel, 80.0%

160   for coal and 65.0 % for biomass (CIBO, 2003).

161   • The condensed steam obtained from the drying stage is used to heat the slurry in the

162   gelatinization stage, giving some heat integration.

163

164   *3.1.3. Artisanal production assumptions*

165   • Artisan methods (i.e. HM, FI and DM) are based on batch processes, with only the drying

166   stage overlapping.

167   • Milling, mixing and gelatinization times are assumed the same as in Industrial

168   Production. Packing time for HM is considered as 30s per sealed pouch –see Table 1.

169   • The working day for single worker scenarios –i.e. HM and FI– is 8h per day (1 shift). DM

170   is assumed to comprise two shifts per day, reaching 16 h/day of operation. The three

171   artisan scales operate for 48 weeks, 5 days a week, as for Industrial Production.

172   • For HM, only one piece of each equipment is available. The batch size is therefore the

173   volume of one food processor, i.e. 1.5×10^{-3} m^3. Solution of the corresponding schedule

174   problem leads to a single batch size of 25 pouches of 0.2 kg, four being the maximum

175   number of batches per day.

176   • FI and DM facilities provide more than one piece of equipment. The initial batch volume

177   for both scenarios is 3.0×10^{-3} m^3. A maximum of three batches of 51 pouches can be

178   produced in a working day by a single worker for FI. DM throughput per facility depends

179   on the number of ovens considered.

180 • For DM, the number of ovens per facility that allows the cheapest operating cost is

181 computed. The upper bound is set as four ovens per facility. No limit on the number of

182 other units is considered. One worker for every two ovens is assumed. Two kind of oven

183 are studied: electric and gas.

184 • No labor costs have been associated to HM and FI scenarios. As 'gig-economy' based

185 scenarios, the workers are the beneficiaries of the economic activity keeping a

186 percentage of the sales (Stanford, 2017).

187

188 Table 1: Unit operations, operating conditions and equipment used for industrial and artisanal

189 dry food manufacturing processes.

Unit Operation	Main Conditions	Equipment	
		Industrial Production (Fig. 2)	Artisanal Production (Fig. 3)
Milling	5 min [16]	Cage mill	Food processor
Dry mixing (1)	15 min [17] Sterile atmosphere (industrial)	Double Cone Blender	Stand Mixer
Wet mixing	Moisture content up to 80 w%[18]	Ribbon Blender	
Gelatinisation	T = 88 °C [19,20] 20 min	Jacketed Stirred Tank	Cooking Pot
Drying	Moisture content: up to 6 w%	Double Drum Dryer	Domestic Oven
Cooling	Atmospheric Temperature	Belt Conveyor with Conditioned Air	Natural Cooling
Dry mixing (2)	15 min [39] Sterile atmosphere (industrial)	Double Cone Blender	Stand Mixer
Packing	30s/pouch	Automatic Packing Machine	Vacuum Sealer

190

191 • HM has no building cost associated as the activity is developed on the worker's kitchen.

192 In the FI case, a monthly payment (kitchen fee) has been added to the operating cost.

193 For DM, the kitchens are rented, assuming a surface of 20m^2 per unit.

194 • HM uses existing personal kitchen instrumentation. However, depreciation of this capital

195 is considered for future replacement of equipment due to use. For FI, no fixed capital is

196 assumed as both equipment and building are rented.

197 • Initial investments, i.e. working capital, are considered equal to the operating cost of one

198 week, the same as inventory cost.

199

200 3.2. Mass and energy balances

201 Mass balances give the amount of each cereal to be milled and the water to be added. No

202 accumulation is assumed in the process units. The amount of materials that enter the

203 equipment is processed during the set residence time –see Table 1. When treatment has

204 finished, the total mass is sent to the next stage. Equation (1) and (2) correspond to the global

205 and component i mass balances, respectively, for J inlet and K outlet streams.

$$\sum_{In} \dot{M}_J - \sum_{Out} \dot{M}_K = \dot{M}_{Accum} + \dot{M}_{Waste} \tag{1}$$

206

$$\sum_{In} \dot{M}_J * x_i - \sum_{Out} \dot{M}_K * x_i = \dot{M}_{Accum} * x_i + \dot{M}_{Waste} * x_i \tag{2}$$

207 where $\dot{M}_J, \dot{M}_K$ are mass fluxes (kg/s) and x_i (w/w) are mass fractions.

208 As thermal processes are involved in manufacturing (i.e. gelatinization, cooling, drying and

209 steam production), energy balances are performed to evaluate heat needs. The first two

210 involve sensible heat alone, while the last two involve both sensible and latent heat transfer

211 (Equation 4).

$$Cp_{prod} = \sum_{i}^{n} x_i * Cp_i \tag{3}$$

212

$$\dot{Q}_{tot} = \dot{Q}_{sensible} + \dot{Q}_{latent} = \dot{M} * Cp_j * \Delta T + \dot{M} * \Delta H^{evap} \qquad (4)$$

213   where Cp_{prod}, Cp_i (J/kgK) are specific heats of the product and single components

214   respectively, ΔT (*K*) is the product temperature change through the process and ΔH is a

215   general phase change enthalpy to represent heats of vaporization (for drying) or gelatinization

216   (10 kJ/kg) (The Quaker Oats Company, 1984). The total energy required by each thermal

217   process is calculated as the sum of the corresponding sensible and latent heats, as defined

218   by Equation (4).

219

220   3.3. Drying operations

221   The drying step demands around 86 % of the heat supplied for the entire manufacture

222   process. Special attention is needed to model dehydration at all scales.

223   For Industrial manufacture, the operation of a double-drum dryer was described

224   considering heat transfer by conduction with a resistance model to define the overall heat

225   transfer coefficient (Almena et al., 2018). This model was used in a design problem that

226   considers the drum dimensions (diameter, length and gap distance between them) and

227   product formulation (i.e. water content of the wet slurry, density of the wet slurry) as input

228   variables. The process variables that minimize the energy consumption while ensuring a target

229   final moisture content (6% w/w) were found. Values for the steam temperature and rotational

230   speed of the drums were then fed into energy and mass balances. Details for the drum dryer

231   design are given in the Supplementary Material (Table S.4 and Table S.5).

232   The operation of the convective oven was described on a similar way, although heat

233   transfer has been defined considering both convection and radiation. A drying rate of 5.24 kg

234   of water/h has been estimated for the domestic oven. Details on how this value has been

235   obtained are presented in the Supplementary Material (Table S.4).

236

237 3.4. Cost estimation

238   Economic evaluation at plant scale was carried out following the procedure found in Almena

239 and Martin (2016), with total annual production cost and total capital estimated using the

240 *Individual Factors* method (Peters and Timmerhaus, 2003; Silla, 2003; Sinnot and Towler,

241 2013). The factors used are shown in Table S.7 and Table S.8 in the Supplementary Material.

242

243 *3.4.1 Total capital*

244   Total capital was defined as the total investment required for construction and start-up, i.e.

245 cost of the equipment, piping and instrumentation, building and land charges, project fees,

246 start-up, contingency and working capital. The equipment purchase and installation is

247 estimated using correlations from Matches' Process Equipment Cost Estimates database

248 (Matches, 2014), and installation factors (see Table S.1 and Table S.9 in the Supplementary

249 Material). Building and land surfaces are estimated assuming an area of three and four times

250 the area occupied by the equipment, thus including safety distances (Mecklenburgh, 1973).

251 Building and land areas are then costed using average cost in the UK (Government of United

252 Kingdom, 2015; Jewson, 2017) –1029.3 \$/m^2 and 482,000 £/hectare (66.2 \$/m^2). For DM fixed

253 capital comprises the refurbishment of kitchens, cost of instrumentation, purchase of auxiliary

254 materials (utilities factor) and one-year rent as deposit.

255

256 *3.4.2   Production cost*

257   The total production (or operating) cost is defined as the annual expense related to

258 manufacture. It comprises: raw materials and packages, electricity and fuel, direct and indirect

259 labor, utilities, supplies, maintenance, laboratory cost, depreciation of the equipment, property

260 taxes, insurance and management cost. Prices of the raw materials are listed in Table S.10

261 (industrial method) and Table S.11 (artisanal method) in the Supplementary Material. Energy

262   prices are also in the Supplementary Material (see Table S.12). Labor cost, equipment

263   depreciation and management cost are not computed using individual factors.

264

265   *3.4.3   Labor cost and equipment depreciation*

266   An organization chart is developed showing direct and indirect labor for the plant (see

267   Figure S.1 in the Supplementary Material) and DM (see Figure S.2). The cost is the average

268   salary for each different job in the year 2017 (Payscale, 2017). Depreciation is computed

269   assuming straight-line depreciation (Peters and Timmerhaus, 2003), while the rest of the cost

270   items are estimated using the corresponding factor.

271

272   *3.4.4   Management cost*

273   For HM and FI scenarios, examples of the 'gig-economy', management is carried out by the

274   company. This follows the approach of Uber® and Airbnb® in other sectors, costing a fee of

275   20% (Huet, 2015) over the baby cereal porridge sales revenue. The seller is the main

276   responsible for the quality and hygiene of the product, as must follow the food hygiene

277   regulations set by the government. The company in charge of management (e.g. the

278   analogous to Uber) would also seek for the highest quality of the products to protect the brand,

279   so part of the management fee would be used to meet the food quality and safety standards,

280   and developing new techniques and products. Management cost at DM and SP/MP scales

281   comprises different items (see Table S.7). Individual factors used for the Industrial Process are

282   shown. For DM, management is necessary to ensuring proper performance of the scattered

283   manufacturing facilities. As a first approach, marketing cost includes the overhead costs of the

284   product (Peters and Timmerhaus, 2003). Quality and hygiene must be controlled and increase

285   the management cost. Due to the degree of complexity, two levels of management have been

286   considered. The lower bound considers each facility as a local business where the owner must

287   fulfil all the standards set by the UK Food Standards Agency (FSA) –i.e. a franchise model–

288   with the supervision of the company that provides the brand. For the upper bound, a single

14

289   company manages the whole business. Specialized technicians are constantly in charge of

290   the food security and quality with two visits per month at each facility. Facilities are divided up

291   to areas with an assumed maximum of 10 branches, with managers in charge of each area

292   (see Figure S.2).

293

294   3.5 Net profit calculation

295   The Net Profit per facility ($\Pi_{bf}{}^{fac}$) is calculated from Equation 5. Value Added Tax

296   ($\%VAT_{bf}$) for baby food is set at the 0% in the UK (Government of United Kingdom, 2017a)

297   and the Corporation Tax Reduction ($\%Tax_{corp.}$) is the 19 % of the Gross Profit (Government

298   of United Kingdom, 2017b).

$$\Pi_{bf}{}^{fac} = \left(1 - \frac{\%Tax_{corp.}}{100}\right)\left[\left(1 - \frac{\%VAT_{bf}}{100}\right)\left(q_{bf}\, p_{bf} - C_{bf}\right)\right] \times \left(\frac{1}{N_{facilities}}\right) \qquad (5)$$

299   Where q_{bf} is the annual quantity of product sold, p_{bf} is the price of the product, C_{bf} is the

300   annual operating cost and $N_{facilities}$ is the number of facilities.

301   For decentralized scenarios, it is assumed that the whole sales revenue is equally divided

302   among all the facilities. $\Pi_{bf}{}^{fac}$ for HM and FI –'gig-economy' scenarios– represent the income

303   per independent contractor, while for DM the revenue goes to the owner of one branch

304   comprising the net of facilities that develops the food production.

305

306   **4.   Results and Discussion**

307   The designed tool generates data for different scenarios. For each, it provides cost

308   estimation, design of equipment, number of facilities and labor requires, energy demand and

309   GHG emissions associated, etc. Different manufacturing scales are compared by finding

310   operating cost per kilogram of product manufactured over the full range of scales. The

311   profitability of one scale over the others is therefore set by the cost per unit, assuming the

312   selling price is constant.

313   The data is analyzed to find points that imply trend variations, such as the highest change

314   on slope (HCS) or the plateau reaching point (PR). We consider the plateau is reached when

315   the value of the derivative remains below 10^{-4}. On this basis, the effect of scale on these

316   characteristic points is going to be studied.

317   The model was used to simulate throughputs from 0.5 kg/h to 6000 kg/h and the different

318   scales of production were compared. In addition, we have employed the model to assess a

319   case analogous to the UK, analyzing how decentralized methods for the production of dry

320   cereal porridge would supply the entire UK demand.

321

322   4.1. Effect of the production scale on the operating cost

323   The production rate is defined as a variable. Figure 4 shows unit costs for each production

324   scenario as a function of the production rate (kg/h). Results show that the steepest slope

325   appears when the throughput grows from very low values. At some point, the slope become

326   less pronounced and keeps flattening until a plateau is reached. The same performance is

327   observed for all manufacturing scales. Artisan manufacturing scales show discontinuities

328   related to the addition of a new facility when the maximum capacity of the net is reached. Such

329   steps also exist for industrial manufacturing, but they are less prominent, so the curves look

330   smoother.

331   HM provides feasible and profitable manufacturing scenarios at very low production rates.

332   The FI case is displaced to the right and production is slightly more expensive. Both

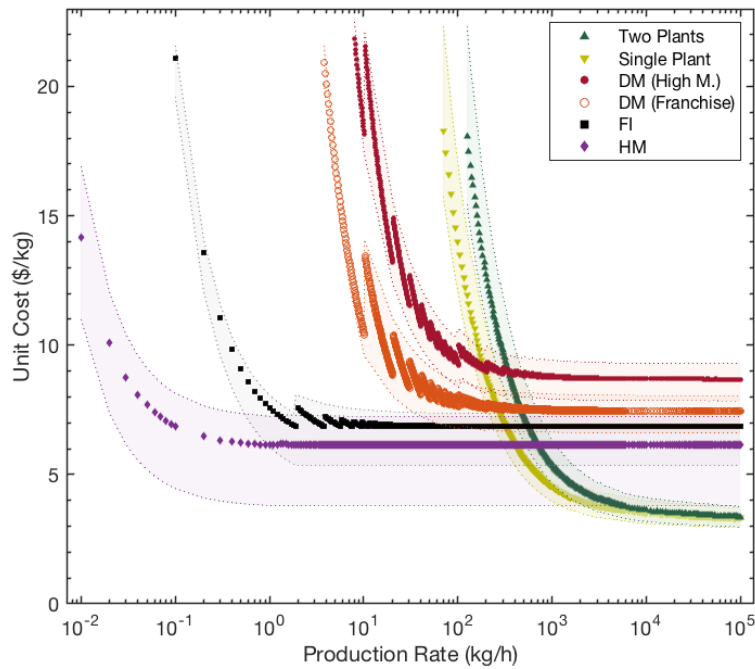333   management cases for DM are also presented in Figure 4.

16

Figure 4: Variation of the unit cost with throughput for different production scales. Unit costs above 10 $/kg (assuming UK market prices) incur in economic loss and thus result in non-profitable production scenarios. According to this, SP is not profitable above 200 kg/h; DM range of operation is profitable below 60 kg/h (high management) and 20 kg/h (franchise - low management); HM and FI result in unit costs below the 10$/kg profitability bound even at very low production rates.

334

335   Results shown correspond to the cheapest solution considering 4 ovens per facility. As

336   expected, the SP scenario gave lower unit costs but reached a plateau at significant higher

337   capacities. For the multi-plant scenario, when the production is halved into two plants of the

338   same capacity operating cost increases when compared to the one plant production – showing

339   economies of scale. The data analysis from Figure 4 is addressed in Section 4.2.

340   *4.1.1 Breakdown of the unit cost*

341   The operating cost per unit has been broken down and analyzed. Costs can be classified

342   as variable and fixed. Variable cost items –e.g. raw materials and package cost– increase with

343   throughput. However, variable cost per unit of product is constant. Fixed cost items are

344   independent of production rate and so fixed cost per unit depends on the production rate

17

345   studied. The overall fixed cost is different for each production scale, increasing with the size

346   of the manufacturing facilities. HM has depreciation of instrumentation as a fixed cost which

347   becomes very expensive at extremely low production rates. The unit cost rapidly decreases

348   as more product is produced. For FI, fixed cost is related to the food incubator fee and the

349   share on the total unit cost is higher than HM. Therefore, this approach requires more product

350   units to spread the fixed cost, i.e. the feasible region starts at higher production rates. DM

351   involves higher fixed cost than the two previous manufacturing scales. Each facility requires

352   labor, rent, instrumentation and management cost; as a result, DM requires higher demand

353   scenarios (ca. 30 kg/h assuming low management) for profitability. The solution for the three

354   artisan manufacturing scenarios shows a maximum when an additional facility is required, and

355   then the effect of that expense is lowered until the maximum capacity is reached. The

356   amplitude is greater as the scale of manufacturing increases, when it requires a higher

357   injection of fixed cost. However, the amplitude of the step decreases with increasing

358   throughput values, as shown in Figure 4. This is also an effect of spreading the fixed cost over

359   a higher number of units produced.

360   Industrial manufacture gives cheaper variable cost (raw material and package prices are

361   lower) so these scales reach a plateau at lower unit cost values. Here the fixed cost share is

362   negligible compared to the variable cost. However, as the overall value of fixed costs is greater

363   than for artisan manufacture, SP and MP need to operate at large production rates to be

364   profitable. Both SP and MP present similar trends. However, the more expensive fixed cost

365   assigned to MP shift the curves to the right, while variable costs contribution remains the

366   same.

367

368   *4.1.2 Unit cost sensitivity analysis*

369   Unit operating costs depend on a number of factors characterized by uncertainty, for example

370   price fluctuations, capital cost or marketing cost. The uncertainty on the estimation of the

371 capital cost is studied by increasing capital up to 40% as upper bound and a decrease of to

372 20% as lower bound. This asymmetric spread towards the positive error is considered as

373 uncertainty is frequently caused by omission of items in design (Peters and Timmerhaus,

374 2003). Marketing costs estimation factor varies depending on the ratio $\left(\frac{quantity\ sold}{N°\ customers}\right)$ for the

375 product sold, increasing when this ratio is very small. Here, it is considered as 15% of

376 production cost, within the uncertainty range: 22% (upper bound) and 5% (lower bound)

377 (Peters and Timmerhaus, 2003). Both effects constitute boundaries for a sensitivity analysis

378 for industrial manufacturing. For artisan manufacturing scales, the same uncertainty factors

379 for capital and management cost are taken. Fluctuation on the raw material price is also

380 assumed. Thus, an increase of 15% over the standard price is taken as upper bound

381 (Nakamura, 2008), while the lower bound would correspond to wholesale price, i.e. a discount

382 of 21% (average gross profit margin for supermarkets) over the standard retail price of raw

383 materials (Chidmi and Murova, 2011; Jindal et al., 2018).

384   Table 2 shows the crossover points for HM, FI and DM plots with the SP & MP curves

385 displayed in Figure 4, including uncertainty bounds. Those points suggest where the artisan

386 manufacturing scales become more cost-effective than industrial scenarios:

387 - HM and FI scenarios are always cheaper than SP for <215 kg/h of production (around

388   52% of UK demand) in the worst-case scenario -i.e. upper bound for artisan scales and

389   lower bound for Single Plant. Uncertainties aside, HM is cheapest for throughputs below

390   400 kg/h.

391 - The DM with low management cost (franchise) is more cost effective than the SP

392   scenario for production rates below 261 kg/h (in the range 174 – 495 kg/h), while when

393   considering a high management cost the cut-off point is reduced down to 194 kg/h,

394   between 125 and 326 kg/h. The importance of management cost in DM is clear.

395

396

Table 2: Crossover points from Figure 4 for each manufacturing scale, including uncertainties: lower bound (lb) and higher bound (hb). A pair of values is associated to each intersection. The upper value corresponds to the x-axis coordinate (*throughput – kg/h*), while the lower is the y-axis coordinate (*unit cost – $/kg*).

Throughput (kg/h) Unit Cost ($/kg)	SP (lb)	**Single Plant**	SP (hb)	MP (lb)	**Multi-Plant (Two Plants)**	MP (hb)
HM (lb)	1,235 3.79	-	> 6,000 3.79	2,160 3.79	-	> 6,000 3.79
Home Manufacturing	-	**407 6.13**	-	-	**723 6.13**	-
HM (hb)	220 7.24	-	409 7.24	383 7.24	-	739 7.24
FI (lb)	400 5.36	-	924 5.36	711 5.36	-	1685 5.36
Food Incubator	-	**321 6.86**	-	-	**566 6.86**	-
FI (hb)	214 7.36	-	394 7.36	375 7.36	-	719 7.36
DM low M. (lb)	252 6.71	-	495 6.65	448 6.67	-	898 6.63
Distributed Manufacturing (low Manag.)	-	**261 7.59**	-	-	**466 7.52**	-
DM low M. (hb)	174 8.36	-	316 8.25	306 8.26	-	581 8.14
DM high M. (lb)	175 8.24	-	326 8.13	316 8.15	-	612 7.94
Distributed Manufacturing (high Manag.)	-	**194 8.99**	-	-	**342 8.99**	-
DM high M. (hb)	125 10.30	-	225 9.86	234 9.81	-	428 9.59
SP (lb)	-	-	-	> 6,000 < 3.19	-	No cross
Single Plant	-	-	-	-	**> 6,000 < 3.60**	-
SP (hb)	-	-	-	265 9.00	-	> 6,000 < 4.10

397

398

399 • For MP (2 plants), crossover points with artisan scenarios are obtained at higher
400   production rates than SP. It can be considered as an alternative to SP for throughput
401   values above 265 kg/h, when the uncertainties start to overlap.

402

403   4.2. Data trend analysis on unit cost curves for each manufacturing scale.

404   The methodology described in Section 4 is applied to the data of Figure 4. For each

405   manufacturing scale curve, HCS and PR points are computed. Figure 5 compares one

406   example of artisan manufacture (i.e. DM at low management) to one of industrial

407   manufacturing (SP).

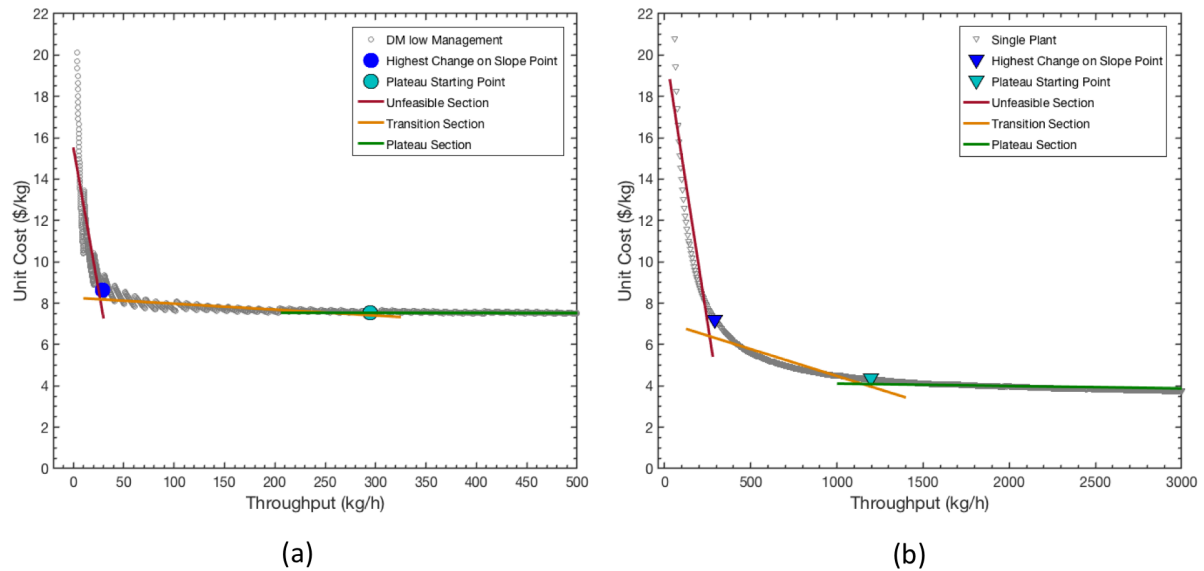
(a)   (b)

Figure 5: Example of how the different operation regions for a manufacturing scale are identified. Graphs show (a) DM low Management (b) Single Plant scenarios. Dark blue marks (dots for (a) and triangles for (b)) represent the biggest change on slope, while light blue ones indicate the plateau starting point. This divides each graph in three regions: 'Unfeasible' (red), 'Transition' (orange) and Plateau ('green'). The lines represent the linear fit of the points belonging to each section.

408

409   HCS and the PR points divide the data in three recognizable regions. The left section

410   comprises the points with the highest slope, where a small increase in the production leads to

411   a significant cost reduction. The scenario is non-feasible, as any profit-seeking company

412   would increase the investment for a greater production if it is cost effective. When the first

413   characteristic point is reached, achieving cost reduction requires a higher increase on

414   productivity, i.e. an important capital injection. Scenario within the transition section, between

415   HCS and PR, could be feasible if it is profitable. The right region represents the plateau, where

416   there is no cost reduction from increasing the production rate. Profits grow with the number of

21

417   product units sold, so companies with no limit on investment and enough market share will

418   invest in bigger production scenarios.

419   The values of HCS and PR points and the linear fitting for unfeasible, transition and plateau

420   regions for all manufacturing scales are compiled in Table 3. HCS points, representing the

421   end of the unfeasible region, are reached at a higher throughput when increasing the facility

422   scale (i.e. max capacity of the manufacturing facility).

423

424   Table 3: High change on slope (HCS) and plateau reaching (PR) points for each

425   manufacturing scale, for which x-axis coordinate (throughput – kg/h) and y-axis coordinate

426   (unit cost – $/kg) are given. This table also shows the linear fitting for each operating region

427   the manufacturing scale is divided in, as the examples shown in Figure 5.

428

	Unfeasible section		HCS (kg/h) ($/kg)	Transition section		PR (kg/h) ($/kg)	Plateau section	
	slope	*intercept*		*slope*	*intercept*		*slope*	*intercept*
HM	-118.85	13.53	0.06 7.41	-0.062	6.44	7 6.14	-2.24×10^{-7}	6.13
FI	-27.75	21.25	0.5 9.07	-0.011	7.14	32 6.87	-2.63×10^{-6}	6.86
DM (low M.)	-0.28	15.53	28.5 8.65	-0.003	8.26	291 7.57	-4.80×10^{-5}	7.55
DM (high M.)	-0.21	19.29	49.2 10.41	-0.002	9.67	557 8.8	-6.96×10^{-5}	8.86
SP	-0.05	20.45	290.0 7.21	-0.003	7.08	1195 4.35	-9.17×10^{-5}	4.23
2P	-0.08	30.62	295.0 9.88	-0.003	8.87	1520 4.70	-9.77×10^{-5}	4.70

429

430

431   HM and FI reached this point for one operating facility, while DM does it for the third and

432   fifth facility depending on the management. For industrial production in single plant and two

433   plants, they are reached at similar overall production rates ($\approx$ 300 kg/h) but at a greater

434 operating cost for the latter. Both HM and SP reach transition region at similar cost values

435 around 7.3 $/kg, but at a throughput difference of four orders of magnitude (0.06 and 290 kg/h

436 respectively). PR points are reached at higher production rates than HCS, but showing a

437 similar behavior. Although the fall in cost for industrial manufacturing scenarios when the

438 plateau appears is higher (4.35 for SP and 4.70 for 2P), it is reached at a very high production

439 rate, nearly three and four times the entire demand of dry baby food in the UK for SP and 2P

440 respectively. On the other hand, artisan manufacturing scenarios achieve all their cost

441 effectivity potential at lower production rates. The cost and throughput values when a plateau

442 is reached increase with the size of the facility. HM does it at 7 kg/h (7 operating facilities) at

443 a cost slightly above 6.1 $/kg and FI when 17 facilities are working with a cost under 6.7 kg/h.

444 For DM, PR points appear at greater throughput and unit cost values especially when the

445 management cost is high. DM at low management reaches the cost floor (7.55 $/kg) when 29

446 facilities operate, while high management requires 55 facilities at a most expensive outcome

447 (8.86 $/kg).

448 The last conclusion we can take from this methodology is the length of the transition region

449 for each manufacturing scale. Industrial manufacturing (see Figure 5) shows the longest

450 section, showing the effect of the economy of scale.

451

452 4.3. Effect of manufacturing scale on total capital

453 Total Capital is used to compare the four production scales addressed here. This value

454 represents the ease of market entry for a company. The investment needed for each

455 manufacturing scale is depicted in Figure 6(a). The highest values correspond to Industrial

456 Manufacturing. Substantial investment is required for construction and start-up of an industrial

457 plant, and this increase when scaling from a single plant to two, with an addition of around 7

458 MM$. The steps result from bigger instrumentation requirements, when the maximum capacity

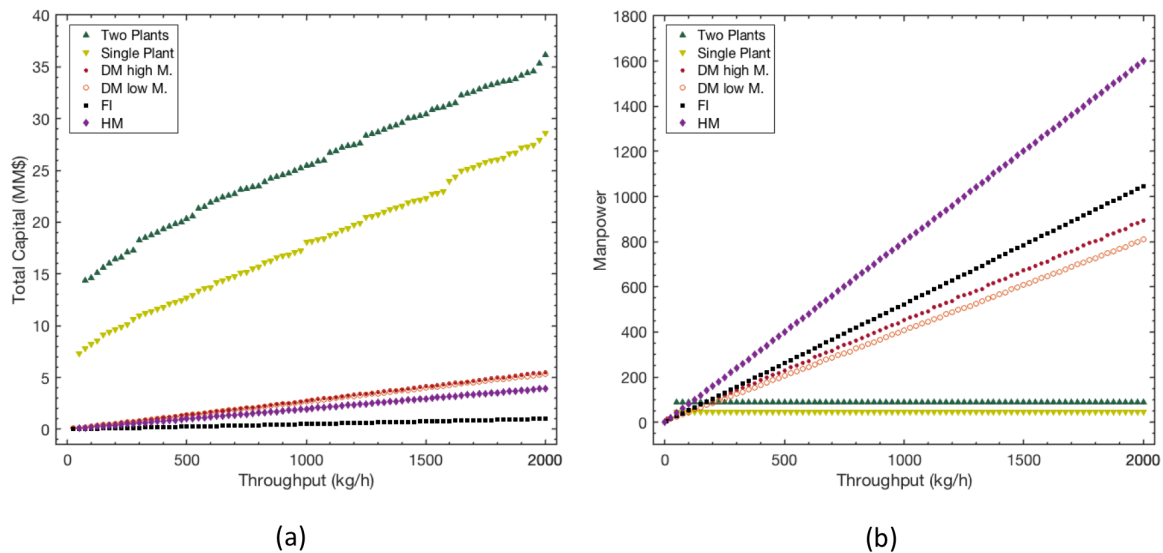459 any of the previous equipment is reached.

460

Figure 6: (a) Total capital and (b) Manpower required for each production scale at different final product´s production rates. Industrial manufacture requires a much larger investment than artisanal production scales, as depicted in (a). Furthermore, the greater number of facilities for small scales requires more labour force, as shown in (b).

461

462   On the other hand, artisan manufacturing scenarios require far less investment –around

463   15% of SP capital– as these decentralized scenarios use rented facilities, and kitchenware is

464   cheaper than industrial equipment. The trend is linear, directly related to the number of

465   facilities. It can be observed that capital is not very sensitive to management cost, resulting in

466   the overlap of the two DM trend lines. HM has capital values close to DM ones due to the high

467   number of facilities– required to produce the same throughput –around 10 to 1. It should be

468   noticed that for HM capital is not required for starting the business as assets are assumed to

469   already exist. However, the depreciation of equipment and the value of the assets are

470   computed as the participants will need to replace them when the lifespan is reached. A

471   different assumption is considered for FI, where assets are rented to the owner, being this fee

472   included on the annual operating cost.

473   Figure 6(b) show the manpower needed at each production rate. Industrial manufacturing

474   labor remains constant, as plants require the same personnel. If two plants are considered,

475   the manpower increases, although not doubling as the senior management is shared. For

476   artisanal manufacturing scenarios, the lowest the scale the highest the manpower required.

477   HM and FI comprise one worker per facility and has the steepest slopes of Figure 6(b).

478   However, being representative of 'gig-economy', labor does not involve any cost as they are

479   the beneficiaries of the economic activity. DM manpower is assumed to be salaried

480   employees, representing the most significant contribution to unit cost for this manufacturing

481   scale. Labor cost becomes even greater those scenarios that include more management

482   personnel.

483
484   4.4. Case study: the UK dry baby food demand scenario.

485   Here, the tool is applied to the demand of dry baby food over the scale of the UK. The

486   whole demand (both dry and wet) of baby food for the year 2015 was 32,000 t (Mintel, 2016),

487   while the market share of dry baby food in the UK is estimated as a 5% of the total production

488   (Minister of Agriculture and Agri-food Canada, 2016). Therefore, a production rate of 418 kg/h

489   is enough to supply the UK dry baby food demand.

490   The seven different scenarios, namely HM, FI, DM, Single-Plant and Multi-plant (splitting

491   from 2 to 4 plants of same capacity) have been assessed and compared. In a UK-based

492   framework, results show that a HM scenario employs 334 cooks, while for FI this is reduced

493   to 219. For DM, 41 facilities spread all over the country with 194 workers –171 for low

494   management– are needed. Results of the mass and energy balance, together with

495   specifications of the equipment are listed in Table S.13 and Table S.14 of the Supplementary

496   Material respectively.

497

498   *4.4.1 Total capital*

499   Total capital corresponding to each UK-based scenario is presented in Figure 7(a). Results

500   show the effect of initial investments (e.g. machinery, land or buildings), as artisanal

501   manufacturing scenarios exhibit much lower values than the industrial scenarios. For example,

502   the DM scenario requires as initial investment the 9.6% of SP capital. The increase in capital

503   required to go from single plant (12.1 MM$) to two plants is 7.4 MM$ (61.4%). When scaling

504   from two plants to three, the rise is smaller –6.4 MM$ (34%)– and increases again when

505   adding an additional plant –7.1 MM$ (26%).

506
507   *4.4.2 Unit operating cost*

508   The production cost for each scale (1 kg of final product as basis) is presented in Figure

509   7(b). The average selling price of dry baby cereal porridge –found in UK supermarkets (Tesco,

510   2016)– is ca. 10 $/kg. The production cost must be below this to achieve profitability. The

511   lowest scale production scenarios, i.e. HM and FI, involve the lowest unit cost. The impact of

512   the labor cost paid and the high management cost as a result of moving from 'gig-economy'

513   to Distributed Manufacturing, increases the production cost. Results thus show HM (6.13 $/kg)

514   and FI (6.86 $/kg) as scenarios with the lowest production cost using artisanal manufacture.

515   DM franchise scenario production cost (7.52 $/kg) is 22.7% greater than HM one, and 45.5%

516   greater when high management is assumed (8.92 $/kg). For SP, the annual operating cost is

517   6.06 $/kg, comprising the cheapest scenario and followed very close by HM (1.2% higher).

518   The maximum unit cost, however, corresponds to the Multiple-Plant cases when there are

519   more than two plants operating. Overall, the high investment required to build a processing

520   plant, measured in terms of financial cost and depreciation, increases cost at low throughput

521   when new plants are added. However, using two plants to supply the UK demand appears

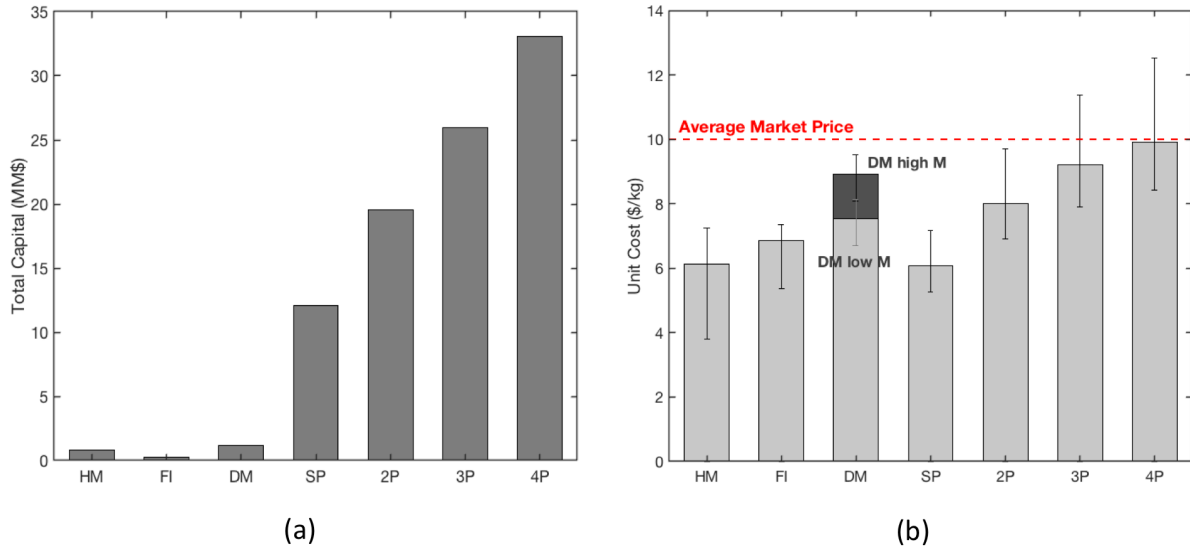522   cheaper than the DM scenario for high management conditions.

523

Figure 7: Total capital (a) and unit operating cost (b) for HM, FI, DM, SP and MP production scenarios under UK dry baby food demand (418 kg/h). In (b) DM has two unit operating cost values for high management (dark bar section and franchise (light bar section). Error bars show the uncertainties for each scale. As shown in (a) DM requires significant lower capital (approx. 10% less) than SP production scenarios. Sharing economy scenarios need even lower total capitals (<1MM$), while increasing the number of plants rises total capital almost linearly. Unit costs for each scale analysed are consistently below average market price (red dashed line in (b)), with HM, FI and DM (franchise) close to SP production operating costs.

524

525   *4.4.3 Net profit*

526   The selling price is kept constant for all the manufacturing scenarios. Nationwide profit –

527   i.e. whole net of facilities profit– and $\Pi_{bf}{}^{fac}$ values are provided. The nationwide annual tax-

528   free profit is 4.97 MM$ (14,850 $/yr.kitchen) for HM and 4.03 MM$ (18,400 $/yr.kitchen) for

529   FI. Although FI has a higher unit cost, the higher production per facility allows greater profit

530   per contractor. DM profitability strongly varies with management cost assumptions, being 1.39

531   MM$ (33,000 $/yr.facility) and 3.18 MM$ (76,830 $/yr.facility) for high and low management

532   case respectively. Single-Plant manufacture gives the highest profit of 5.06 MM$/year, while

533   for two plants it decreases to 2.57 MM$/year (1.28 MM$/year.plant).

534

535   *4.4.4 Energy demand and carbon footprint at manufacture stage*

536   Table 4 shows the results of energy demand and carbon footprint associated for the UK

537   scenario. Multiple fuels have been considered. For artisanal manufacturing, electric oven and

538   gas oven are assessed. Regarding industrial manufacturing, there is the possibility of using

539   several energy sources for the steam fired boiler. Similar individual numbers have been

540   obtained for all scenarios. However, for the annual energy consumption at each scale the

541   difference is substantial. Natural gas is assumed to be used for all scales in the economic

542   results previously discussed. For artisan manufacture, a domestic gas oven is assumed to

543   have an efficiency of 45% (Ko and Lin, 2003), while electric ovens are more energy effective

544   (60%) (The Carbon Trust, 2015). The double drum dryer is assumed to require 1 kg of steam

545   per 0.71 kg of water evaporated (Ramli and Daud, 2014).

546   The carbon footprint for on each scenario was estimated from calculated energy using the

547   UK Government Greenhouse Gas (GHG) Conversion Factors (Government of the United

548   Kingdom, 2017c). This provides the GHG emissions data that every manufacturer must report

549   to the UK government. The carbon footprint of the industrial process is the lowest, producing

550   0.530 kg CO_2e per kg of product manufactured, as shown in Table 4. An additional plant

551   increases the emissions by 4% as the energy efficiency slightly drops.

552   Among the alternative fuel sources, a boiler fed with biomass (pellets) carries the least

553   carbon footprint, despite being less energy effective. The use of this kind of boiler at industrial

554   scale is still challenging. For the alternative manufacture methods, environmental impact

555   factors related to these scenarios give emissions around 15% higher than industrial ones. HM

556   carries the least emissions within artisanal manufacture with 0.596 kg CO_2e/kg. FI and DM

557   slightly increase the carbon load by 2% and 3%. If electric ovens are used for drying, the

558   energy demand decreases by 40% from natural gas, but the environmental impact rises by

559   33%.

560

Table 4: Carbon Footprint of HM, FI, DM, SP and MP (two plants) at the manufacturing stage.
Artisanal production scales show results for both electric and natural gas oven cases.

Manufacturing Scenario	Total Energy	Electricity Consumption	Fuel Consumption	$C_{Electrici}$	C_{fuel}	C_{Total}
	kJ/kg	kWh/kg	kg/h		$kg\,CO_{2e}/kg$	
HM						
-electric oven-	7002.0	1.945	–	0.801	–	0.801
-gas oven-	9086.0	0.208	2.316	0.086	0.474	0.560
FI						
-electric oven-	7077.2	1.966	–	0.810	–	0.810
-gas oven-	9120.3	0.263	2.270	0.109	0.464	0.573
DM						
-electric oven-	7059.2	1.961	–	0.808	–	0.808
-gas oven-	9102.3	0.258	2.271	0.106	0.465	0.571
SP						
-natural gas-	8946.0	0.102	97.8 $\left(m^3/h\right)$	0.042	0.488	0.530
-fuel oil-	8550.9		88.3		0.648	0.690
-diesel-	8550.9		79.8		0.608	0.650
-coal-	8141.7		142.8		0.737	0.779
-biomass-	9935.9		232.1		0.034	0.076
MP (2P)						
-natural gas-	9117.1	0.149	97.8 $\left(m^3/h\right)$	0.062	0.488	0.549
-fuel oil-	8722.0		88.3		0.648	0.709
-diesel-	8722.0		79.8		0.608	0.670
-coal-	8312.8		142.8		0.737	0.799
-biomass-	10107.0		232.1		0.034	0.095

5. Overview and future food manufacture trends and challenges

One of the issues that centralized manufacturing faces is the search for differentiation of products. Mass customization, delivering differentiated or personalized products with near

569   mass production efficiency, is the goal for many companies in the current diversified

570   marketplace (Tseng and Hu, 2014). However, mass customization with centralization still

571   creates lengthy supply chains. Distributed Manufacture (DM) systems could solve many of the

572   issues of centralized production. Local variation or mass customization can be created from

573   decentralized and small-scale manufacture. Short Food Supply Chains (SFSC) (Sellitto et al.,

574   2018) and Alternative Food Networks (AFN) (Jarosz, 2008) comprise alternative scenarios

575   that shorten the supply chain and suggest the food industry might adopt a 'good food network'

576   based on decentralization (Sage, 2003) and eco-localism (Curtis, 2003) as a path to

577   environmental, economic and social sustainability. Recent studies also point out that AFN's

578   can contribute to ensure food security (Cerrada-Serra et al., 2018; Moragues-Faus and

579   Carroll, 2018). Although the balance between increased production costs and decreased

580   transport cost in decentralized scenarios needs further study, DM could well be used for

581   emerging SFSC or specialized supply chains, e.g. dry supply chains (where products are

582   distributed/stored in dried/powder form and rehydrated closer to the consumers) or

583   frozen/refrigerated chains (decreasing road mileage, cost and GHG emission of refrigerated

584   vehicles).

585   At the smallest manufacturing scale per facility, a very large number of "production units"

586   (labor and stores) is required to duplicate the output of a plant, which can generate new jobs

587   and stronger social impacts in local communities. However, the concept of the 'gig-economy',

588   understood as "crowdwork" or "work-on demand via app", eliminates boundaries for

589   manpower, enhancing market flexibility, albeit at the cost of economic security for many

590   workers (Dokko et al., 2015). Advances in information and communication technologies (ICT)

591   have allowed the contact of an indefinite number of costumers and workers on a global basis

592   (De Stefano, 2016), and the additional concept of a 'sharing economy' (also called

593   'collaborative consumption'), which involves peer-to-peer based activity of sharing the access

594   to goods coordinated by ICTs (Hamari et al., 2016), has overcome the limitation of capital

595   investment at low production rates. These ideas set the basis for different manufacturing

596   models on food processing, by analogy with other industry sectors, e.g. Uber and Airbnb.

597   Modular manufacturing (Baldea and Edgar, 2017) and additive manufacturing (Femmer et al.,

598   2015) are different up-to-date approaches for seeking a decentralized, scalable and flexible

599   production in other sectors of the industry, consolidating these new trends.

600   Distributed based scenarios will involve unavoidable challenges too. The number of

601   facilities required (here 334 for HM) requires time and organization and some regulatory

602   framework (Srai et al, 2016). Although the smallest scale assessed here, involving peer-to-

603   peer services, has been shown to contribute large economic benefits in other sectors,

604   governments will still need to develop policies to protect consumers and providers. The

605   smaller the manufacture scale, the more difficult maintaining the food safety is (Cottee, 2014).

606   This could be the subject of future research. A minimum standard for product quality could be

607   also compromised, only relying on the market self-regulation by review and rating feedback

608   from customers and suppliers via ICTs apps. Localisation implies a closer relationship

609   between manufacturer and consumer (Albrecht and Smithers, 2018). The sellers should

610   provide a high-quality and safe product, while consumers loyalty would support the producer

611   selling on quality and naturalness despite a potential increase on the prize (Groves, 2008).

612

613   **6.   Conclusions**

614   A model-based tool for the design, simulation and cost estimation of manufacturing process

615   at several scales of production has been developed and used to assess the profitability of four

616   different scenarios, from decentralized manufacturing (HM, FI and DM) to centralized

617   manufacturing (SP and MP), in the production of a dried food. Operating regions, namely

618   unfeasible, transition and plateau, have been identified for each manufacturing scale.

619   Crossover points showing the boundaries of operation for decentralized scales to be more

620   profitable than industrial scenarios are also predicted. Results show that total decentralization

621   (HM and FI), can be an alternative to centralization by providing competitive operating cost

622   and increased manpower. The DM scenario represents a competitive alternative to the current

623   centralized production, when its management cost is moderate. The low capital required and

624   the sensible number or facilities comprising the net suggest this could be easier to apply at

625   the UK scale. For energy use and carbon load, artisanal manufacture-based scenarios are not

626   advantageous when compared to the industrial processing. Results revealed that splitting the

627   production into two or more plants does not give any advantage for manufacturing in economic

628   terms.

629   Overall, this work shows the capability and flexibility of the proposed methodology to

630   assess the profitability of different manufacturing scenarios at a wide range of production

631   scales. The method allows the variation of multiple parameters, helping in the complex

632   decision between centralized manufacturing or decentralized manufacturing systems. The

633   results demonstrate how different production scales generate profits; although the

634   assumptions and estimations are all taken from reliable sources, they might hardly fit a real

635   industrial system with a high level of accuracy, the method shows that it is possible to generate

636   models at these different scales. A further study of the entire food supply chain for each

637   scenario would show the economical and energy saving potential of the alternative

638   manufacturing methods assessed.

639

643

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Centralized and distributed food manufacture: A modelling platform for technological, environmental and economic assessment at different manufacturing scales.

A. Almena[a], P.J. Fryer[a], S. Bakalis[b], E. Lopez-Quiroga[a]*.

[a]School of Chemical Engineering, University of Birmingham, B15 2TT, UK
[b]Faculty of Engineering, University of Nottingham, NG7 2RD, UK

*e.lopez-quiroga@bham.ac.uk

Unit Cost Correlations.

Table S.1. _Correlation for equipment cost estimation (Matches, 2014)._

Cage Mill	$C_c(\$_{2014}) = 5{,}657.1\,d^2 + 4{,}057.1\,d - 8{,}671.4$	S1
Double Cone Mixer	$C_{cm}(\$_{2014}) = 3848.50\,V^{0.42}$	S2
Ribbon Blender	$C_{rb}(\$_{2014}) = 2{,}410.10\,V^{0.60}$	S3
Jacketed and Agitated Reactor	$C_r(\$_{2014}) = 2{,}410.10\,V^{0.60}$	S4
Double drum dryer	$C_{dd}(\$_{2014}) = 22{,}425.73\,S^{0.38}$	S5
Conveyor belt & conditioned air	$C_{cb}(\$_{2014}) = 484{,}950.46\,Q_{rem}^{\;0.73}$	S6
Packing Machine	Price 58,000 \$ (Alibaba.com, 2016) $C_p(\$_{2017}) = N^o{}_{units} \times Price$	S7
Boiler	Pressure up to 150 psi: $C_b(\$_{2014}) = 11.20\,\dot V + 213{,}015$	S8
	Pressure 150 to 600 psi: $C_b(\$_{2014}) = 22.02\,\dot V + 474{,}139$	S9
	Pressure 600 to 1500 psi: $C_b(\$_{2014}) = 25.21\,\dot V + 621{,}581$	S10
Vertical Vessel –Silos and Intermediate tank–	$C_v(\$_{2014}) = 231.50\,W^{0.61}$	S11
Marshall and Swift Cost Index (IM&S)	$IM\&S_{year} = 51.39\,year - 101{,}795$	S12
	$C_{MSCI}(\$_{2016}) = C_{MSCI}(\$_{2014})\dfrac{IM\&S_{2016}}{IM\&S_{2014}}$	S13

All the cost obtained using these correlations are given as Free on Board (FOB) incoterm, obtained in dollars for the year 2014. For this reason, a shipping fee must be added as 1.1 factor (Silla, 2003), together with an update of this expense for the current year. The update is made using the Marshall & Swift Equipment Index (Economic Indicators, 2012). This data finished in the year 2012, so an extrapolation is made as a valid approach.

Artisanal Process Equipment.

Table S.2. *Cooking instrumentation features.*

Instrument	Price ($)	Capacity	Electricity consumption (kW)
Food Processor	195.00	1.5 l	0.9
Saucepan	27.00	5 l	N/A
Induction hob	435.00	4 zones	4.6
Oven	780.00	70 l	3.65 / Nat Gas Fed
Vacuum Sealer	69.00	1 bag/min	0.12

Table S.3. *Features of Double drum dryer (Gouda, 2016) and Domestic oven.*

Model #1			
Drum diameter	0.5 m	Drum length	0.5 m
Min Rotational speed	2.2 rpm	Max Rotational speed	22.0 rpm
Min power consumption	4.0 kW	Max power consumption	7.5 kW
Model #2			
Drum diameter	0.5 m	Drum length	1.0 m
Min Rotational speed	2.2 rpm	Max Rotational speed	22.0 rpm
Min power consumption	5.5 kW	Max power consumption	7.5 kW
Model #3			
Drum diameter	1.0 m	Drum length	1.0 m
Min Rotational speed	1.5 rpm	Max Rotational speed	15.0 rpm
Min power consumption	8.0 kW	Max power consumption	35.0 kW
Model #4			
Drum diameter	1.0 m	Drum length	2.0 m
Min Rotational speed	1.5 rpm	Max Rotational speed	15.0 rpm
Min power consumption	15.0 kW	Max power consumption	35.5 kW
Model #5			
Drum diameter	1.0 m	Drum length	3.0 m
Min Rotational speed	1.5 rpm	Max Rotational speed	15.0 rpm
Min power consumption	22.0 kW	Max power consumption	43.3 kW
Model #6			
Drum diameter	1.5 m	Drum length	3.0 m
Min Rotational speed	1.5 rpm	Max Rotational speed	15.0 rpm
Min power consumption	37.0 kW	Max power consumption	100.0 kW
Model #7			
Drum diameter	1.5 m	Drum length	4.0 m
Min Rotational speed	1.5 rpm	Max Rotational speed	15.0 rpm
Min power consumption	44.0 kW	Max power consumption	100 kW

Domestic Oven	
Capacity	70 l
Power (electric oven)	5.10 kW
Tray surface	0.275 m^2
Heat transfer surface	0.550 m^2
Global heat transfer coefficient	28.0 W m^{-2} K^{-1}

Table S.4. *Double drum dryer model.*

Energy supply at the drum *(kW)*
$$Q_{drum} = U\, A\, \Delta T_{lm}$$
Overall heat transfer coefficient *(U [=] W /m² °C)*
$$\frac{1}{U} = \frac{1}{h_{i_0}} + r_{di}\frac{d_0}{d_i} + \frac{1}{\kappa_{drum}} + r_{d0} + \frac{1}{\kappa_{d-s}}$$
Mean condensation film coefficient inside horizontal tubes *(W /m² °C)* (Sinnot and Towler, 2013)
$$h_{i_0} = 0.76\, k_L \left[\frac{\rho_L(\rho_L - \rho_V)g}{\mu_L\, \Gamma_h}\right]^{1/3}$$
Conduction coefficient for the dryer drum *(κ_m [=] W /m °C ; d_0 [=] m)*
$$\kappa_{drum} = \frac{2\,\kappa_m}{d_0 \ln\left(d_0/d_i\right)}$$
Conduction coefficient for the drum *($\kappa_{slurry\ gel}$ [=] W /m °C ; $\tau_{slurry\ gel}$ [=] m)*
$$\kappa_{d-s} = \frac{\kappa_{slurry\ gel}}{\tau_{slurry\ gel}}$$
Internal fouling resistance *(m² °C / W)* (Sinnot and Towler, 2013)
$$r_{di} = 1/f_{steam} = 1/3250$$
External fouling resistance *(m² °C / W)* (Sinnot and Towler, 2013)
$$r_{d0} = 1/f_{slurry} = 1/5000$$
Heat transfer surface *(m²)*
$$A = (X_{blades})\, 2\pi d_0 L$$
Logarithmic mean temperature difference *(°C)*
$$\Delta T_{lm} = \frac{(T_{steam} - T_{Dry}) - (T_{Steam} - T_{Gel})}{\log\left[\frac{(T_{steam} - T_{Dry})}{(T_{Steam} - T_{Gel})}\right]}$$
Drying rate *(kg/s)*
$$\dot{m}_w{}^f = \left(Q_{drum} - Q_{sensible\ gel}\right)\Big/ \Delta H_{vap}{}^{H_2O}$$
Final moisture content of slurry *(kg water / kg slurry)*
$$x_w{}^f = \left[\frac{m_{slurry}{}^0 x_w{}^0 - \left(\frac{60}{\omega_{drum} X_{blades}}\right)\dot{m}_w{}^f}{\rho_{gel}\, A\, \tau_{slurry\ gel} - \left(\frac{60}{\omega_{drum} X_{blades}}\right)\dot{m}_w{}^f}\right]$$
Objective function
$$J_{DD} = \sqrt{\sum(x_w{}^f - x_w{}^{target})^2} + \sqrt{\sum(\dot{m}_w{}^f - \dot{m}_w{}^{target})^2} + \left(\frac{1}{1000}\right)\sqrt{\sum(Q_{drum} - Q_{dry})^2}$$

Table S.5. *Double drum dryer design*

Design Variable (x_i)	Lower Bound (lb_i)	Upper bound (ub_i)
T_{steam}	100	300
ω_{drum}	$Model\ \#\ \omega_{drum}{}^{min}$	$Model\ \#\ \omega_{drum}{}^{max}$

Continuous Variable	Value
Q_{dry}	Energy balance (function of production rate)

Discrete Variable	Value
d_0	$Model\ \#$ feature
L	$Model\ \#$ feature

Double Drum Dryer Design Routine	
Initial guess	multi-shot
Tolerance	10^{-14}
Algorithm	Interior point (Matlab)
Solution	$\min (J_{DD})$

Stopping Criteria	Boundary
Maximum Dry equipment surface	100 m^2
Max Diff Heat supply and needed	$\sqrt{\left(\dfrac{N_{DDD} * Q_{Drums} - Q_{dry}}{Q_{dry}}\right)^2} < 1$

Design Solution: Double Drum Dryer and Boiler minimum cost
$\min \{(C_{dd} + C_b)\}$

Table S.6. Domestic convective oven operation

Constant rate of mass loss model (Carson et al., 2006): Apparent heat transfer coefficient.	$$h_a = \frac{-\phi\, L\,(T_s)}{T_\infty - T_s}$$
Water to evaporate in a batch	$$m_w{}^{evap} = m_{Cereal\ Flour}{}^{batch}\left(\frac{1}{x_w{}^o} - \frac{1}{x_w{}^{target}}\right)$$
Heat required	$$Q_{dry} = m_w{}^{evap}\left[\Delta H^{evap} + Cp_w\left(T_{surface} - gel\right)\right]$$
Drying time	$$t_{Dry} = \frac{Q_{dry}}{h_a\,\dfrac{A_{Drying}}{N_{batch}}tray\left(T^\infty{}_{oven} - T_{surface}\right)}$$
Drying rate	$$\dot{m}_w{}^{evap} = \frac{m_w{}^{evap}}{t_{Dry}}$$

Table S7. *Individual Factors for Operating Cost Estimation.*

	Name of Cost Item	Individual Factor
Manufacturing Cost (MC) [M$/year]	Cost of Raw Materials [1,2,3,4]	$\sum m_i \times p_i$
	Direct Labour [3,4]	$N_{workstation} \times N_{Shift} \times Salary$
	Indirect Labour [3,4]	$\sum N_j \times Salary_j$
	Utilities [1,2,3,4]	Mass and Energy balances
	Supplies [1,2,3,4]	$0.009 \times I$
	Maintenance [1,2,3,4]	$0.06 \times C_{Ph}$
	Laboratory [4]	$0.20 \times Direct\ Labour$
	Depreciation (linear) [1,2,3,4]	$C_{Equipment}/12$
	Property taxes [4]	$0.01 \times I$
	Insurance [1,2,3,4]	$0.01 \times I$
Management Cost (G) [M$/year]	Marketing [1,2,3,4]	$0.15 \times C$
	Administrative Cost [3,4]	$1.10 \times (\sum N_k \times Salary_k)$
	Financing Cost [1,2,3,4]	$0.08 \times PT$
	Research and Development [4]	$0.03 \times I$
	Hygiene & Quality Tech. [3,4]	$N_{technician} \times N_{Shift} \times Salary$
	Head and Directives [3,4]	$\sum N_k \times Salary_k$
Operating Cost (C) = MC + G		

HM (1)   FI (2)   DN (3)   SP&MP (4)

Individual Factors Used for Manufacturing Plant cost estimation.

Table S.8. *Individual Factors for Capital Estimation.*

	Name of Cost Item	Individual Factor
Physical Capital (C_Ph) *[M$]*	Cost of Equipment [3,4]	$\sum N_l \times p_l$
	Installation and Shipping [4]	$\sum \left(N_l \times p_l \times F_l \times F_{shipping} \right)$
	Piping [4]	$0.45 \times C_{Equipment}$
	Measuring Instrumentation [4]	$0.20 \times C_{Equipment}$
	Thermal Insulation [4]	$0.07 \times C_{Equipment}$
	Electricity Facilities [3,4]	$0.15 \times C_{Equipment}$
	Building Expenses [4]	$3 \times A_{Equip} \times C_{Edification}$
	Land Cost [4]	$4 \times A_{Equip} \times C_{Indust\ Land}$
	Utilities Installation [3,4]	$0.40 \times C_{Equipment}$
	Refurbishment[3] (DSB, 2017)	$(1700 + 55 \times m^2_{kitchen} + 700) N_{kitchen}$
	Deposit rent[3] (Quality, 2017)	$12\ \frac{mo.}{year} \times 30\ \frac{£}{m^2 mo.} \times m^2_{kitchen} \times N_{kitch}$
	Engineering and Supervision [4]	$0.20 \times C_{Ph}$
Direct Capital (C_D)		$C_{Ph} + C_{Eng}$
	Contractor's fee [4]	$0.07 \times C_D$
	Contingency [4]	$0.20 \times C_D$
	Previous Research [4]	$0.12 \times I$
	Start-up Cost [4]	$0.08 \times I$
Fixed Capital (I)		$C_D + C_{Cont\ fee} + C_{Conting} + C_{Prev\ Res} + C_{Star-up}$
Working Capital (P_C) *Time Basis: 1 Month*	Pre-ordered Raw Mat and Utilities [4]	${C_{Raw\ Mat}}/{q} \times {q}/{12}$ $q \equiv annual\ prod\ [t/year]$
	Material under manufacture [4]	$1/2 \times {MC}/{q} \times f \times {q}/{12}$ $f \equiv manufacturing\ cycle\ [y^{-1}]$
	Inventory [4]	${MC}/{q} \times {q}/{12}$
	Inventory [1,2,3]	${Operating\ Cost}/{52}$
	Pending Sales [4]	$1/2 \times {V}/{q} \times {q}/{12}$ $V \equiv Sales\ revenue\ [M\$\ y^{-1}]$
	Cash in Bank [4]	${MC}/{q} \times {q}/{12}$
Total Capital (P_T) = $I + P_C$		

* HM (1) FI (2) DM (3) SP&MP (4)

Installation Factors for industrial equipment.

Table S.9. *Installation factors for equipment (Silla, 2003).*

Unit	Name in Silla´s table	Installation Factor
Mills	Crushers, classifiers, mills	1.3
Dry Mixers	Blenders	1.3
Wet mixer	Blenders	1.3
Stirred tanks	Reactors, Kettles (CS)	1.9
Dryers	Dryers, other	1.4
Cooling	Miscellaneous	2.0
Package machine	Miscellaneous	2.0
Boiler	Boilers	1.5
Silos	Tanks, Storage (SS)	1.5
Intermediate tanks	Tanks, Storage (CS)	2.3

Wholesaling Cost of Raw Materials for Industrial Manufacture.

Table S.10. *Prices of raw materials for industrial manufacture.*

Raw material	Price ($/t)	Source
Oat	241.13	Indexmundi, 2016a
Rice	460.10	Indexmundi, 2016b
Sugar	344.09	Indexmundi, 2016c
Skimmed milk powder	2574.00	Global Dairy Trade, 2016
Dry malt extract (food quality)	3500.00	Hunan Huacheng Biotech Inc, 2016
Palm oil flakes (food quality)	1045.00	Suoya Biological Technology, 2016
Water	2.57×10^{-3} ($/m3)	South West Water, 2016
Packing paper boxes	0.15 ($/box)	Dongguan Fuliter Paper Prod., 2016
Packing cans	0.58 ($/can)	XYN Can Packaging, 2016
Packing plastic boxes	0.20 ($/box)	Shenzhen Huacheng Pack., 2016

Retail Cost of Raw Materials for Artisanal Manufacture.

**Table S11.** *Supermarket raw materials price (Tesco, 2017).*

Raw Material	Price ($/kg)
Rice flour	1.58
Oat flour	2.64
Rice (raw)	1.97
Oat (raw)	0.99
Sugar	0.78
Milk powder	6.18
Dry malt extract	9.36
Vacuum bag (200 g)	0.21 $/unit
Palm oil (food)	6.47

Price of energy sources.

Table S.12. *Price and GHG conversion factors for different energy sources.*

Fuel	Low Heating Value (kJ/kg) (Boundy, et al. 2011)	Price (£/kWh) (Government of United Kingdom, 2017b)	GHGs factor (kgCO$_2$e/kg) (Government of United Kingdom, 2017b)
Natural Gas	36,625 (kJ/m^3)	1.771 e-2	0.20463
Heavy Fuel Oil	38,700	3.830 e-2	0.28499
Diesel	42,791	4.423 e-2	0.26751
Coal	22,732	0.960 e-2	0.34149
Biomass (pellets)	17,209	5.033 e-2	0.01270
Electricity	-	8.363 e-2	0.41205

Labour Plant Manufacture Scale.
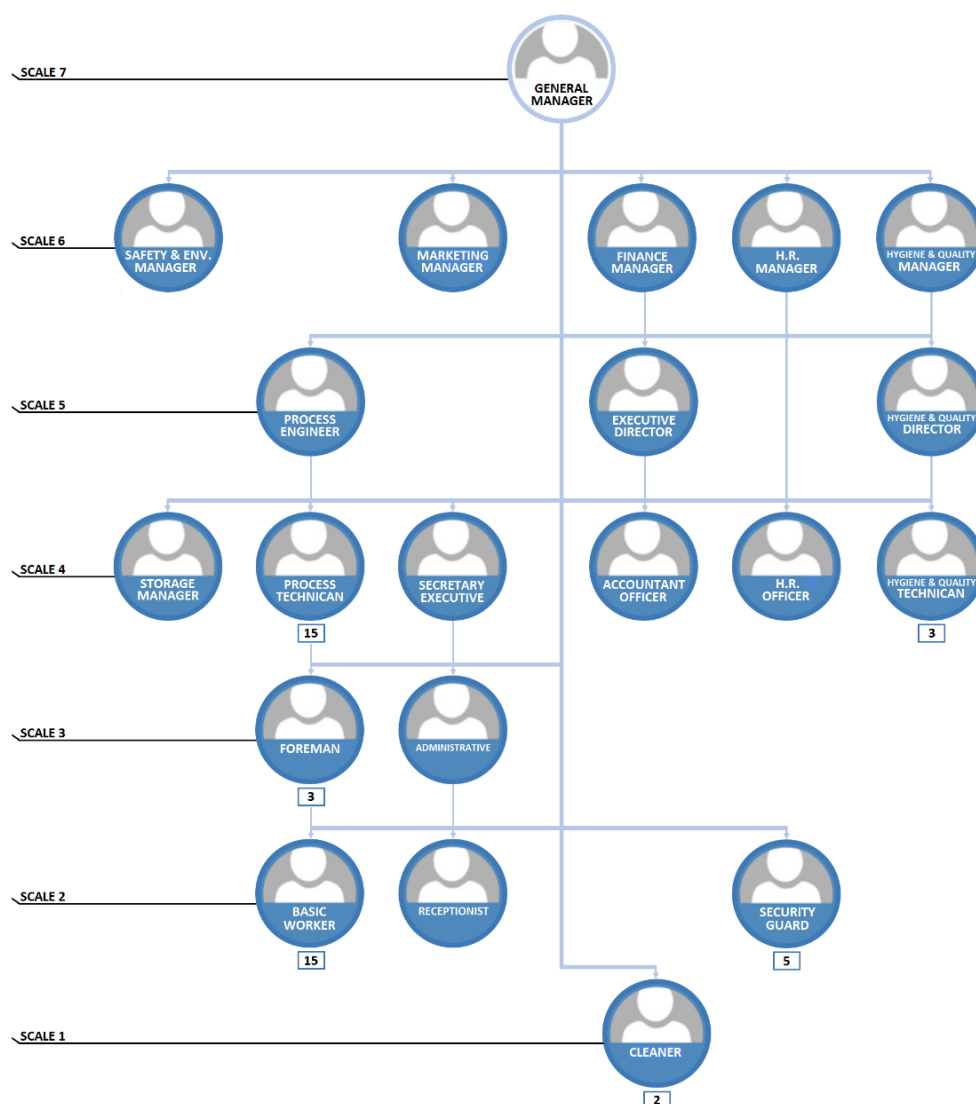
Figure S.1. *Company Organisation Chart for Plant Manufacture.*

Labour Plant Distributed Net Scale (High Manufacture Cost).
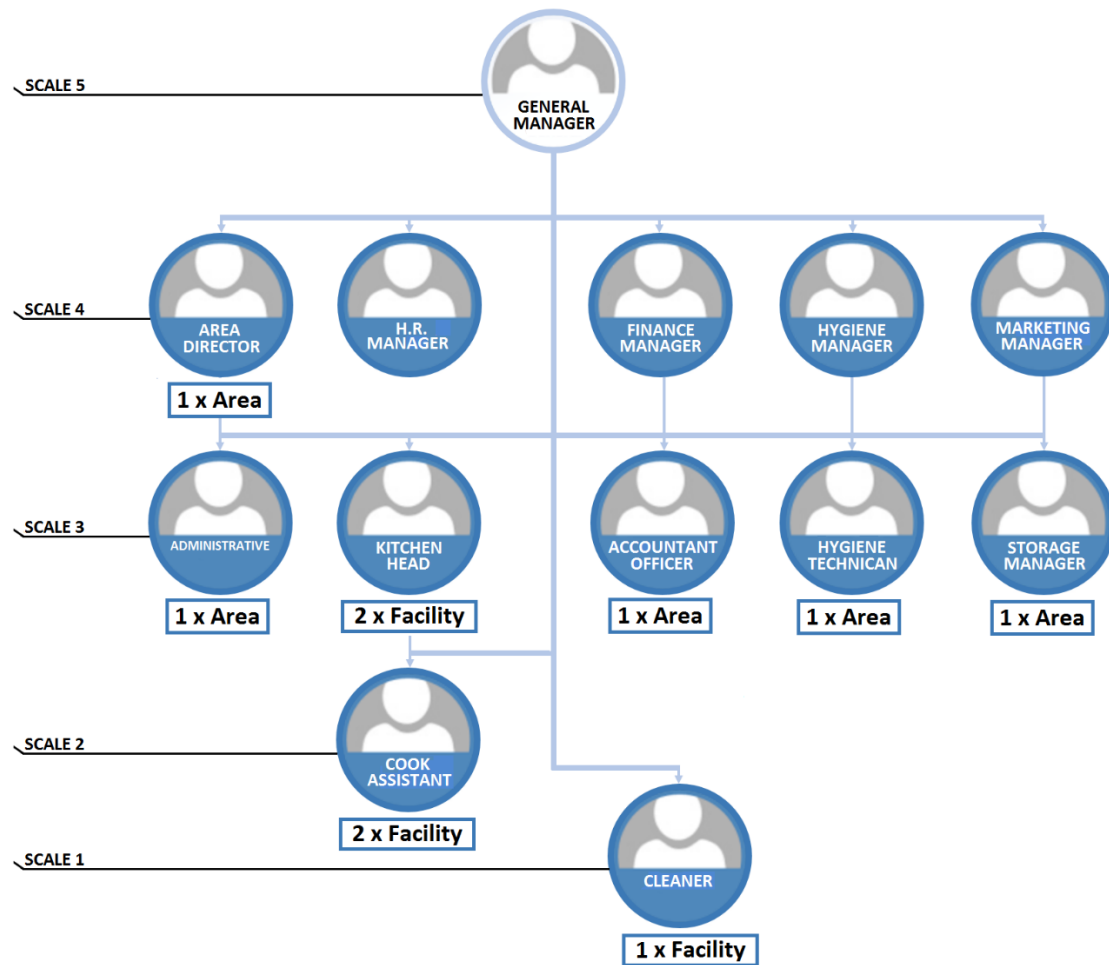
Figure S.2. _Company Organisation Chart for Distributed Net with High Manufacture Cost._

Table S.13. Results of the mass and energy balances for Single-Plant scale in a scenario analogous to the UK.

STREAM	1	2	3	4	5	6	7
Oat (kg/h)	157.7	156.1	-	-	1.6	154.5	-
Rice (kg/h)	-	-	49.6	49.1	0.5	48.6	-
Water (kg/h)	-	-	-	-	-	-	812.4
Palm oil (kg/h)	-	-	-	-	-	-	-
Sugar (kg/h)	-	-	-	-	-	-	-
Malt extract (kg/h)	-	-	-	-	-	-	-
Milk powder (kg/h)	-	-	-	-	-	-	-
Moisture (%)	12.0	12.0	12.0	12.0	12.0	12.0	100.0
Total mass (kg/h)	157.7	156.1	49.6	49.1	2.1	203.1	812.4
Temperature (k)	293.2	293.2	293.2	293.2	293.2	293.2	293.2
Pressure (bar)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vapour quality	0	0	0	0	0	0	0
Heat (kJ/h)	-	-	-	-	-	-	-

STREAM	8	9	10	11	12	13	14	15
Oat (kg/h)	1.5	153.0	1.5	151.5	-	3.8	147.7	147.7
Rice (kg/h)	0.5	48.1	0.5	47.6	-	1.2	46.4	46.4
Water (kg/h)	8.1	804.3	8.0	796.3	791.3	5.0	0	0
Palm oil (kg/h)	-	-	-	-	-	-	-	-
Sugar (kg/h)	-	-	-	-	-	-	-	-
Malt extract (kg/h)	-	-	-	-	-	-	-	-
Milk powder (kg/h)	-	-	-	-	-	-	-	-
Moisture (%)	82.6	82.6	82.6	82.6	100.0	82.4	10.6	10.6
Total mass (kg/h)	10.1	1,005.4	10.0	995.4	791.3	10.0	194.1	194.1
Temperature (k)	293.2	293.2	361.2	361.2	393.2	393.2	393.2	293.2
Pressure (bar)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vapour quality	0	0	0	0	1	0	0	0
Heat (kJ/h)	-	2.72×10^5			1.83×10^6		-3.41×10^4	-

STREAM	16	17	18	19	20	21	22	23
Oat (kg/h)	-	-	-	-	-	-	-	146.1
Rice (kg/h)	-	-	-	-	-	-	-	45.8
Water (kg/h)	-	-	-	-	-	-	-	-
Palm oil (kg/h)	12.8	12.7	-	-	-	-	-	12.6
Sugar (kg/h)	-	-	85.2	84.3	-	-	-	83.6
Malt extract (kg/h)	-	-	-	-	4.2	4.2	-	4.2
Milk powder (kg/h)	-	-	-	-	-	-	126.5	125.2
Moisture (%)	0.0	0.0	1.8	1.8	2.0	2.0	2.5	6.0
Total mass (kg/h)	12.8	12.7	85.2	84.3	4.2	4.2	126.5	417.5
Temperature (k)	293.2	293.2	293.2	293.2	293.2	293.2	293.2	293.2
Pressure (bar)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vapour quality	0	0	0	0	0	0	0	0
Heat (kJ/h)	-	-	-	-	-	-	-	-

STREAM	24	25	26	27	W1	W2	W3
Oat (kg/h)	1.6	$2{,}087 \times (7.0 \times 10^{-3}$ kg/pack h)	-	1.6	-	-	-
Rice (kg/h)	0.5	$2{,}087 \times (2.2 \times 10^{-3}$ kg/pack h)	-	0.5	-	-	-
Water (kg/h)	-	-	-	-	614.6	614.6	614.6
Palm oil (kg/h)	0.1	$2{,}087 \times (6.0 \times 10^{-3}$ kg/pack h)	0.1	-	-	-	-
Sugar (kg/h)	0.8	$2{,}087 \times (4.0 \times 10^{-2}$ kg/pack h)	0.9	-	-	-	-
Malt extract (kg/h)	4.2×10^{-2}	$2{,}087 \times (2.0 \times 10^{-3}$ kg/pack h)	4.2×10^{-2}	-	-	-	-
Milk powder (kg/h)	1.3	$2{,}087 \times (6.0 \times 10^{-2}$ kg/pack h)		-	-	-	-
Moisture (%)	6.0	6.0	1.6	12.0	-	-	-
Total mass (kg/h)	4.3	$2{,}087 \times (0.20$ kg/pack h)	300.0	2.1	-	-	-
Temperature (k)	293.2	293.2	293.2	293.2	431.9	431.9	373.9
Pressure (bar)	1.00	1.00	1.00	1.00	4.98	4.98	4.98
Vapour quality	0		0	0	1	0	0
Heat (kJ/h)	-	-	-	-	-1.83×10^{6}		-2.72×10^{5}

Table S14. Features and variables of design of all the units involved in Single-Plant manufacture. The design variable is given in the cost correlation units.

Equipment	Feature 1	Feature 2	Design Variable	Power
Cage Mill (x4)	Length = 3.10 m	Width = 2.24 m	Diameter = 2.00 m	4.66 kW
Double Cone Blender (op. 2)	Length = 2.00 m	Width = 1.20 m	V = 5.30 ft³	2.24 kW
Ribbon Blender	Length = 1.63 m	Width = 0.71 m	V = 12.80 ft³	3.73 kW
Stirred Tank	Diameter = 0.60 m	Height = 1.20 m	V = 100.39 gal(US)	0.44 kW
Double Drum Dryer	Model #4 (x1) T_{Steam} = 139.7 °C	Rot Speed = 3.06 rpm M_{Steam} = 0.17 kg/s	Dry Surface = 135.30 ft²	17.31 kW
Cooling Conveyor	Length = 5.25 m	Width = 1.38 m	$Q_{removed}$ = 6.80 kW	4.47 kW
Double Cone Blender (op. 8)	Length = 2.00 m	Width = 1.20 m	V = 5.30 ft³	2.24 kW
Pack. Machine	Length = 6.20 m	Width = 1.10 m	Cost = 58,000 $/unit	3.70 kW
Steam Boiler	Diameter = 3.01 m IPS 4	81 tubes / 1 tube pass Fuel need = 97.8 m³/h	Capacity = 2500 lb/h	Natural Gas
Oat Silo	Diameter = 3.30 m	Height = 13.20 m	Weight = 36,970 kg	-
Rice Silo	Diameter = 1.95 m	Height =7.80 m	Weight = 8,629 kg	-
Sugar Silo	Diameter = 2.85 m	Height = 11.40 m	Weight = 24,527 kg	-
Milk Powder Silo	Diameter = 2.85 m	Height = 11.40 m	Weight = 24,527 kg	-
Malt Extract Silo	Diameter = 1.05 m	Height = 4.20 m	Weight = 1,675 kg	-
Palm Oil Silo	Diameter = 1.65 m	Height = 6.60 m	Weight = 5,497 kg	-
Oat Flour Tank	Diameter = 0.45 m	Height = 0.90 m	Weight = 124 kg	-
Rice Flour Tank	Diameter = 0.30 m	Height = 0.60 m	Weight = 49 kg	-
Mixed Flour Tank	Diameter = 0.45 m	Height = 0.90 m	Weight = 122 kg	-
Wet Slurry tank	Diameter = 0.75 m	Height = 1.50 m	Weight = 421 kg	-
Dry and Cold Slurry Tank	Diameter = 0.45 m	Height = 0.90 m	Weight = 122 kg	-
Final Pre-Packed Product Tank	Diameter = 0.60 m	Height = 1.20 m	Weight = 243 kg	-

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