

## Chapter 2

# Risk Pooling in Business Logistics

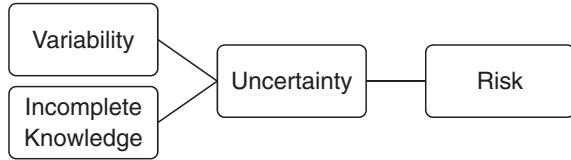
**Abstract** Risk pooling in business logistics can reduce the total variability of demand and/or lead time and thus uncertainty and risk (the possibility of not achieving business objectives) by consolidating individual variabilities (measured with the standard deviation) of demand and/or lead time. These individual variabilities are consolidated by aggregating demands (demand pooling) and/or lead times (lead-time pooling). This reduction in uncertainty allows to reduce inventory without reducing the customer service level (product availability) or to increase the service level without increasing the inventory or a combination of both and to cope with product variety. Risk pooling can be achieved by (1) inventory pooling, (2) virtual pooling, (3) transshipments, (4) centralized ordering, (5) order splitting, (6) component commonality, (7) postponement, (8) capacity pooling, (9) product pooling, and (10) product substitution. These risk-pooling methods can reduce demand and/or lead-time uncertainty. Risk pooling is explained by the Minkowski-inequality, the subadditivity property of the square root of non-negative real numbers, and the balancing effect of higher-than-average and lower-than-average demands and/or lead times. The ten risk-pooling methods can be implemented everywhere along the supply chain and mainly pertain to the value activities storage (1), transportation (2 and 3), procurement (4 and 5), production of goods and services (6, 7, and 8), and sales and distribution (9 and 10).

**Keywords** Variability • Uncertainty • Risk • Standard deviation • Aggregation • Customer service level • Inventory reduction • Minkowski-inequality • Subadditivity • Value chain

### 2.1 Defining Risk Pooling

Among others Hempel (1970, p. 654), Wacker (2004, p. 630), and the references they give make requirements for a “good” definition. “A ‘good’ [formal conceptual] definition [...] is a concise, clear verbal expression of a unique concept that

**Fig. 2.1** Relating variability, uncertainty, and risk



can be used for strict empirical testing” (Wacker 2004, p. 631). Hempel (1970, p. 654) requires inclusivity, exclusivity, differentiability, clarity, communicability, consistency, and parsimony.

Previous attempts to define risk pooling do not seem to satisfy these requirements. They merely describe its causes,<sup>1</sup> effects,<sup>2</sup> or aim,<sup>3</sup> only target demand pooling<sup>4</sup> and/or equate risk pooling with inventory pooling<sup>5</sup> and the square root law.<sup>6</sup> Moreover they do neither define nor differentiate between variability, uncertainty, and risk. Tallon (1993, pp. 192, 199f.), for instance, equates variability with uncertainty.

For a detailed treatment of previous research’s shortcomings please refer to Oeser (2011, pp. 11ff.).

Also the literature offers various definitions of and confusion about the terms variability, variance, or volatility,<sup>7</sup> uncertainty,<sup>8</sup> and risk.<sup>9</sup>

Lead-time and demand uncertainty may arise from lead-time and demand variability or incomplete knowledge.<sup>10</sup> “Uncertainty is the inability to determine the true state of affairs of a system”.<sup>11</sup> “Uncertainty caused by variability is a result of inherent fluctuations or differences in the quantity of concern. More precisely, variability occurs when the quantity of concern is not a specific value but rather a

<sup>1</sup> Nahmias (2005 p. 334), Anupindi et al. (2006, p. 168), Romano (2006, p. 320), Simchi-Levi et al. (2008, p. 48), Wisner et al. (2009, p. 513), Bidgoli (2010, p. 209).

<sup>2</sup> Gerchak and He (2003, p. 1027), Özer (2003, p. 269), Romano (2006, p. 320), Simchi-Levi et al. (2008, p. 48), Cachon and Terwiesch (2009, pp. 325, 350), Bidgoli (2010, p. 209).

<sup>3</sup> Chopra and Meindl (2007, p. 212), Cachon and Terwiesch (2009, p. 321).

<sup>4</sup> Flaks (1967, p. 266), Gerchak and Mossman (1992, p. 804), Gerchak and He (2003, p. 1027), Özer (2003, p. 269), Nahmias (2005, p. 334), Anupindi et al. (2006, p. 187), Chopra and Meindl (2007, p. 212).

<sup>5</sup> Anupindi et al. (2006, p. 168).

<sup>6</sup> Wisner et al. (2009, p. 513).

<sup>7</sup> Hubbard (2009, pp. 84f.).

<sup>8</sup> Knight (2005, pp. 19ff.), Haimes (2009, pp. 265ff.), Hubbard (2010, pp. 49f.).

<sup>9</sup> Wagner (1997, p. 51), Knight (2005, pp. 19ff.), Hubbard (2009, pp. 79ff.; 2010, pp. 49f.).

<sup>10</sup> Cf. Haimes (2009, p. 265).

<sup>11</sup> Haimes (2009, p. 265).

population of values”.<sup>12</sup> Lead-time and demand uncertainty may lead to economic risk,<sup>13</sup> the possibility<sup>14</sup> of a negative deviation from expected values or desired targets<sup>15</sup> (Fig. 2.1).

The corporate target is expected profit (cf. Fig. 2.3), the difference of expected revenue and expected cost.<sup>16</sup> The possibility of a positive deviation from an expected value constitutes a chance.<sup>17</sup>

“Outside of finance, volatility may not necessarily entail risk—this excludes considering volatility alone as synonymous with risk”.<sup>18</sup> For a detailed treatment of the confusion about the terms uncertainty and variability please refer to Haimes (2009, pp. 265ff.).

Despite the costs risk pooling entails,<sup>19</sup> it may reduce variability and thus uncertainty and expected (ordering, inventory holding, stockout, and backorder) costs<sup>20</sup> and/or increase expected revenue (product availability, fill rate, service level)<sup>21</sup> and thus expected profit.<sup>22</sup>

This book defines risk pooling in business logistics as consolidating individual variabilities (measured with the standard deviation<sup>23</sup>) of demand and/or lead time in order to reduce the total variability<sup>24</sup> they form and thus uncertainty and risk<sup>25</sup>

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<sup>12</sup> Haimes (2009, p. 266).

<sup>13</sup> Bowersox et al. (1986, p. 58), Delfmann (1999, p. 195), Pishchulov (2008, p. 17).

<sup>14</sup> Wagner (1997, p. 51).

<sup>15</sup> Cf. e.g. Wagner (1997, p. 51), Köhne (2007, p. 321).

<sup>16</sup> Wagner (1997, p. 52).

<sup>17</sup> Wagner (1997, p. 51).

<sup>18</sup> Hubbard (2009, p. 91).

<sup>19</sup> Kim and Benjaafar (2002, p. 16), Cachon and Terwiesch (2009, p. 328).

<sup>20</sup> Eppen (1979), Chen and Lin (1989), Tagaras (1989), Tagaras and Cohen (1992, pp. 1080f.), Evers (1996, p. 114, 1997, pp. 71f.), Cherikh (2000, p. 755), Eynan and Fouque (2003, p. 704), Kemahloğlu-Ziya (2004), Bartholdi and Kemahloğlu-Ziya (2005), Wong (2005), Jiang et al. (2006, p. 25), Thomas and Tyworth (2006, p. 253), Chopra and Meindl (2007, pp. 324ff.), Pishchulov (2008, pp. 8, 17f.), Schmitt et al. (2008, pp. 14, 20), Simchi-Levi et al. (2008, p. 48), Cachon and Terwiesch (2009, pp. 325, 331, 344, 350).

<sup>21</sup> Krishnan and Rao (1965), Tagaras (1989), Tagaras and Cohen (1992, pp. 1080f.), Evers (1996, pp. 111, 114; 1997, pp. 71f.; 1999, p. 122), Eynan (1999), Cherikh (2000, p. 755), Ballou and Burnetas (2000, 2003), Xu et al. (2003), Ballou (2004b, pp. 385–389), Wong (2005), Kroll (2006), Reyes and Meade (2006), Chopra and Meindl (2007, pp. 324ff.), Cachon and Terwiesch (2009, pp. 325, 329, 344, 350).

<sup>22</sup> Anupindi and Bassok (1999), Cherikh (2000, p. 755), Lin et al. (2001), Eynan and Fouque (2003, pp. 704, 707, 2005, p. 98), Kemahloğlu-Ziya (2004), Bartholdi and Kemahloğlu-Ziya (2005), Özen et al. (2005), Chopra and Meindl (2007, pp. 324ff.), Simchi-Levi et al. (2008, pp. 234–238), Cachon and Terwiesch (2009, p. 331), Yang and Schrage (2009, p. 837).

<sup>23</sup> Sussams (1986, p. 8), Romano (2006, p. 320).

<sup>24</sup> Cf. e.g. Chopra and Meindl (2007, p. 336).

<sup>25</sup> Cf. e.g. Pishchulov (2008, p. 18).

(the possibility of not achieving business objectives<sup>26</sup>). The individual variabilities are consolidated by aggregating<sup>27</sup> demands<sup>28</sup> (demand pooling<sup>29</sup>) and/or lead times<sup>30</sup> (lead-time pooling<sup>31</sup>). Consolidating and aggregating mean “combining several different elements [...] into a whole”.<sup>32</sup>

This definition uses “[t]he standard deviation [as it] is the most commonly used and the most important measure of variability”.<sup>33</sup> Furthermore, pooling independent random variables does not change total variability measured with the variance. Of course, one could argue that the measuring unit of the variance is squared and therefore difficult to interpret and that the standard deviation and not the variance is used to calculate safety stock. Pooling variabilities measured with the range may even increase total variability.

Zinn et al. (1989, p. 2) and Chopra and Meindl (2007, p. 307) consider the standard deviation a measure of uncertainty. Cachon and Terwiesch (2009, pp. 331f., 282f.) and Chopra and Meindl (2007, p. 307) use the derived coefficient of variation (standard deviation divided by mean) as a measure for demand variability or uncertainty.

As individual variabilities<sup>34</sup> and not individual risks are pooled, the term risk pooling may be misleading. Nonetheless, this book uses it, because it is conventional.

Risk pooling is also referred to as “statistical economies of scale”,<sup>35</sup> “portfolio efficiencies”,<sup>36</sup> “Pooling Efficiency through Aggregation” or “Principle of Aggregation”,<sup>37</sup> and “Impact of Aggregation on Safety Inventory”.<sup>38</sup>

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<sup>26</sup> Wagner (1997, p. 51).

<sup>27</sup> Cf. e.g. Anupindi et al. (2006, p. 167), Chopra and Meindl (2007, p. 336).

<sup>28</sup> Gerchak and Mossman (1992, p. 804), Swaminathan (2001, p. 131), Hillier (2002b, p. 570), Randall et al. (2002, p. 56), Gerchak and He (2003, p. 1027), Özer (2003, p. 269), Chopra and Sodhi (2004, pp. 55, 60), Nahmias (2005, p. 334), Anupindi et al. (2006, pp. 167, 187), Romano (2006, p. 320), Chopra and Meindl (2007, p. 177), Pishchulov (2008, pp. 8, 18, 26), Simchi-Levi et al. (2008, pp. 48, 196, 281, 348), Yu et al. (2008, p. 1), Yang and Schrage (2009, p. 837), Bidgoli (2010, p. 209).

<sup>29</sup> Evers (1997, pp. 55, 57, 1999, pp. 121f.), Benjaafar and Kim (2001), Benjaafar et al. (2004a, p. 1442, 2004b, p. 91), Chopra and Sodhi (2004, pp. 59ff.), Tomlin and Wang (2005, p. 37), Gürbüz et al. (2007, p. 302), Van Mieghem (2007, pp. 1270f.), Ganesh et al. (2008, p. 1134), Cachon and Terwiesch (2009, p. 332), Wanke and Saliby (2009, p. 690), Yang and Schrage (2009, p. 837).

<sup>30</sup> Thomas and Tyworth (2006, p. 254).

<sup>31</sup> Evers (1999, pp. 121f.), Cachon and Terwiesch (2009, p. 336).

<sup>32</sup> Soanes and Hawker (2008).

<sup>33</sup> Gravetter and Wallnau (2008, p. 109).

<sup>34</sup> Gerchak and He (2003, p. 1028).

<sup>35</sup> Eppen (1979, p. 498), Eppen and Schrage (1981, p. 52), Evers (1994, p. 51), Özer (2003, p. 269), Rabinovich and Evers (2003a, p. 206).

<sup>36</sup> Eppen and Schrage (1981, p. 52).

<sup>37</sup> Anupindi et al. (2006, pp. 187, 189).

<sup>38</sup> Chopra and Meindl (2007, p. 318).

In the next section ten risk-pooling methods will be identified, defined, and subsumed under the definition established in this section.

## 2.2 Defining Methods of Risk Pooling

After thoroughly reviewing more than 600 publications<sup>39</sup> it is concluded that apart from (1) inventory pooling (IP) risk pooling in business logistics can also be achieved by (2) virtual pooling (VP), (3) transshipments (TS), (4) centralized ordering (CO), (5) order splitting (OS), (6) component commonality (CC), (7) postponement (PM), (8) capacity pooling (CP), (9) product pooling (PP), and (10) product substitution (PS). For each of these terms there are numerous, often ambiguous synonyms. Please refer to Oeser (2011, pp. 25f.) for a detailed listing.

As highlighted in the definition given in the introduction, risk-pooling (methods) may take advantage of demand pooling (DP) and/or lead-time pooling (LP). DP aggregates stochastic demands, so that higher-than-average demands may balance lower-than-average ones.<sup>40</sup> LP balances higher-than-average and lower-than-average lead times, i.e., a late-arriving order may be compensated by an early-arriving one,<sup>41</sup> so that safety stock can be reduced, inventory availability increased, or both.<sup>42</sup>

Cachon and Terwiesch (2009, p. 336) consider consolidated distribution and delayed differentiation types of LP: Lead times between the supplier and the retail stores in the direct-delivery model are combined to a single lead time between the supplier and the distribution center (DC) in the consolidated-distribution model.<sup>43</sup> However, actually (forecast) demands are pooled over or during the outside-supplier lead time.<sup>44</sup> Thus it is likely that higher-than-average and lower-than-average demands balance each other and inventory can be reduced for a given service level (DP).

The ten identified risk-pooling methods will now be defined using these risk-pooling building blocks of DP and LP:

(1) Inventory pooling is the combination of inventories and satisfying various demands from it in order to reduce inventory holding and shortage costs through

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<sup>39</sup> Oeser (2012, pp. 153f.).

<sup>40</sup> Evers (1997, p. 55), Chen and Chen (2003).

<sup>41</sup> Evers (1999, p. 122).

<sup>42</sup> Evers (1997, p. 71, 1999, p. 122).

<sup>43</sup> Cachon and Terwiesch (2009, p. 339).

<sup>44</sup> Eppen and Schrage (1981), Schwarz (1989), Schoenmeyr (2005, p. 4), Gürbüz et al. (2007, p. 293).

risk pooling.<sup>45</sup> It can e.g. be achieved through inventory<sup>46</sup> or warehouse (system) centralization<sup>47</sup> or selective stock keeping respectively specialization.<sup>48</sup> The latter strives to reduce inventory carrying cost treating products differently without reducing the service level substantially. For example, products with a low turnover might be stocked at only a few locations due to cost considerations.<sup>49</sup> Inventories are consolidated and stochastic demands aggregated, as they are satisfied from the consolidated inventory.<sup>50</sup> Thus demand variabilities may balance each other (DP). The lead times to the separate inventories are pooled to the lead time to the consolidated stock according to Cachon and Terwiesch's (2009, pp. 336, 339) notion of LP. But actually this is DP during the replenishment lead time. Inventory pooling does not pool lead times, so that their variabilities cannot balance each other according to Evers (1997, pp. 69ff.; 1999, p. 121) and Wanke and Saliby (2009, pp. 678f.). The risk-pooling effect on (safety) stock levels evoked by inventory pooling or centralization can be quantified with the square root law (SRL),<sup>51</sup> portfolio effect (PE),<sup>52</sup> and inventory turnover curve.<sup>53</sup>

(2) Virtual pooling extends a company's warehouse or warehouses beyond its or their physical inventory to the inventory of other own or other companies' locations<sup>54</sup> by means of information and communication technologies (ICT),<sup>55</sup> dropshipping,<sup>56</sup> and cross-filling.<sup>57</sup> "[D]emand across [these locations] is pooled, which smoothes demand fluctuations".<sup>58</sup> If virtual pooling entails cross-filling, it may pool lead times. However, this corresponds to transshipments and is considered next.

<sup>45</sup> Benjaafar and Kim (2001, p. 13), Kim and Benjaafar (2002, p. 12), Gerchak and He (2003, p. 1027), Benjaafar et al. (2005), Anupindi et al. (2006, p. 191), Pishchulov (2008, pp. 8, 17), Cachon and Terwiesch (2009, p. 322).

<sup>46</sup> Benjaafar et al. (2004a, p. 1438).

<sup>47</sup> Eppen (1979), Benjaafar and Kim (2001, p. 13), Taylor (2004, pp. 304f.), Reiner (2005, p. 434), Heil (2006).

<sup>48</sup> Anupindi et al. (2006, pp. 191f.), Chopra and Meindl (2007, pp. 322ff.).

<sup>49</sup> Pfohl (2004a, pp. 122f.).

<sup>50</sup> Pishchulov (2008, pp. 8, 17).

<sup>51</sup> Maister (1976), Das (1978), Eppen (1979), Zinn et al. (1989), Evers and Beier (1993), Evers (1995), Croxton and Zinn (2005).

<sup>52</sup> Zinn et al. (1989), Ronen (1990), Mahmoud (1992), Tallon (1993), Evers (1996, 1997), Evers and Beier (1998), Tyagi and Das (1998), Das and Tyagi (1999), Wanke (2009), Wanke and Saliby (2009).

<sup>53</sup> Ballou (1981, 2000, 2004a, b, pp. 381f., 2005).

<sup>54</sup> Caddy and Helou (2000, p. 1715), Planning and Reporting (2001), Kroll (2006).

<sup>55</sup> Memon (1997), Christopher (1998, p. 135), Planning and Reporting (2001), SDM (2001), Frontline Solutions Europe (2002), Electrical Wholesaling (2003), Mason et al. (2003), Fung et al. (2005), Kroll (2006), Cioletti (2007), Cachon and Terwiesch (2009, pp. 350, 469).

<sup>56</sup> Planning and Reporting (2001), Randall et al. (2002, 2006), Netessine and Rudi (2006).

<sup>57</sup> Ballou (2004b, pp. 335, 385–389).

<sup>58</sup> Randall et al. (2002, p. 56).

(3) Transshipments are inventory transfers among locations (e.g. between warehouses or stores) *inter alia* in case of a stockout. They pool both demands across locations or retailers<sup>59</sup> (by permitting alternative locations to satisfy customer demands) and lead times (by providing the whole system with the possibility of partial stock replenishments) and allow a company to remain close to customers.<sup>60</sup>

(4) Centralized ordering<sup>61</sup> or order pooling places joint orders for several locations and later allocates the orders (perhaps by a depot) to the requisitioners or distribution points according to current demand information.<sup>62</sup> The allocation decision is postponed and stochastic demands can be treated in an aggregate form until it is made. This reduces uncertainty and system stock “because of a portfolio effect over the lead time from the supplier”,<sup>63</sup> “portfolio efficiencies”,<sup>64</sup> or “statistical economies of scale”.<sup>65</sup> As explained at the beginning of this section, centralized ordering or consolidated distribution does not entail LP, so that lower-than-average supplier lead times may not balance higher-than-average ones.

(5) Order splitting is simultaneously partitioning a replenishment order into multiple orders with multiple suppliers<sup>66</sup> or into multiple deliveries (scheduled-release).<sup>67</sup> The single order and thus its lead time are split into multiple orders or deliveries and their lead times, so that the variabilities of these lead times may balance each other.<sup>68</sup> Consequently, order splitting only pools lead times, not demands.<sup>69</sup>

(6) Component commonality designs products that share parts or components,<sup>70</sup> so that these common components can be used for several products.<sup>71</sup> Thus demand for the individual components is aggregated or pooled<sup>72</sup> to the

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<sup>59</sup> Tagaras (1989), Tagaras and Cohen (1992), Evers (1997, 1999), Hong-Minh et al. (2000), Çömez et al. (2012a, 2012b), Wanke and Saliby (2009), Yang and Schrage (2009, p. 837).

<sup>60</sup> Evers (1997, 1999, p. 121), Wanke and Saliby (2009).

<sup>61</sup> Eppen and Schrage (1981, p. 51), Erkip et al. (1990, p. 381), Ganeshan et al. (2007, p. 341), Gürbüz et al. (2007, p. 293).

<sup>62</sup> Eppen and Schrage (1981), Cachon and Terwiesch (2009, pp. 336–341).

<sup>63</sup> Eppen and Schrage (1981, p. 67).

<sup>64</sup> Eppen and Schrage (1981, p. 52).

<sup>65</sup> Eppen (1979, p. 498), Eppen and Schrage (1981, p. 52).

<sup>66</sup> Evers (1999, p. 123), Thomas and Tyworth (2006, p. 245), Qi (2007).

<sup>67</sup> Hill (1996), Chiang (2001), Mishra and Tadikamalla (2006), Thomas and Tyworth (2007, p. 188).

<sup>68</sup> Evers (1999, p. 122).

<sup>69</sup> Evers (1999, pp. 123f.).

<sup>70</sup> Srinivasan et al. (1992), Jönsson et al. (1993), Meyer and Lehnerd (1997), Ma et al. (2002), Mirchandani and Mishra (2002), Kim and Chhajed (2001), Swaminathan (2001, p. 131), Labro (2004), Van Mieghem (2004), Ashayeri and Selen (2005), Chew et al. (2006), Humair and Willems (2006), Simchi-Levi et al. (2008, p. 348).

<sup>71</sup> Grotzinger et al. (1993, p. 524).

<sup>72</sup> Yang and Schrage (2009, p. 837).

demand for the (fewer) generic common component(s).<sup>73</sup> For example, in order to reduce demand variability for power supply units (PSUs) a common PSU for both 220 and 110 volts could be used for electrical appliances sold in Europe and the U.S. instead of using 220-volt PSUs for Europe and 110-volt ones for the U.S.<sup>74</sup> Common components are also used in building modular book shelves.<sup>75</sup> Component commonality seems to be especially popular in the car industry.<sup>76</sup>

(7) Postponement in general means delaying a decision in logistics, procurement, production, or distribution in order to be able to use more accurate information because of a shorter forecast period and an aggregate forecast, especially in industries with high demand uncertainty,<sup>77</sup> and committing resources rather to demand than to a forecast.<sup>78</sup> The opposite strategy of holding finished goods at locations close to customers in anticipation of sales is called speculation.<sup>79</sup> Aggregate forecasts usually are more accurate than disaggregate ones<sup>80</sup> because of statistical balancing effects, statistical economies of scale, or risk pooling.<sup>81</sup> For further explanations please refer to e.g. Neumann (1996, pp. 9f.), Sheffi (2004, p. 93), Alicke (2005, p. 44), Nahmias (2005, p. 55), Donnellan et al. (2006, p. x), Simchi-Levi et al. (2008, p. 60), and Schuckel (2010, p. 152). Postponement allows to ship a single common generic product longer down the supply chain and change it to individual products (differentiate it) more responsively according to more recent demand information later.<sup>82</sup> On the preceding levels of the supply chain the demands for the individual products are aggregated to the demand for the generic product (DP<sup>83</sup>), which fluctuates less, since the stochastic fluctuations of the individual demands balance each other to a certain extent because of the risk-pooling

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<sup>73</sup> Dogramaci (1979, p. 129), Guerrero (1985, p. 409), Vakharia et al. (1996, p. 15), Kreng and Lee (2004), Labro (2004, p. 363), Kulkarni et al. (2005, p. 247), Graman and Magazine (2006, p. 1074), Bidgoli (2010, p. 21).

<sup>74</sup> Thonemann (2010, p. 444).

<sup>75</sup> Thonemann (2010, slides to chap. 8, chart 11).

<sup>76</sup> Mayne et al. (2008), Thonemann (2010, p. 448).

<sup>77</sup> Pfohl (1994, p. 143), Swaminathan and Tayur (1998), Swaminathan (2001, pp. 129f.), Sheffi (2004, pp. 95f., 100), Anupindi et al. (2006, pp. 192f.), Chopra and Meindl (2007, p. 362), García-Dastugue and Lambert (2007, pp. 57f.), Piontek (2007, pp. 86f.), Simchi-Levi et al. (2008, p. 346), LeBlanc et al. (2009, p. 19).

<sup>78</sup> Bucklin (1965), Van Hoek (2001, p. 161).

<sup>79</sup> Bucklin (1965).

<sup>80</sup> Lawrence and Zanakis (1984, p. 25), Neumann (1996, pp. 9f.), Swaminathan (2001, pp. 126f.), Sheffi (2004, pp. 93f.), Alicke (2005, p. 44), Nahmias (2005, p. 55), Anupindi et al. (2006, pp. 168, 187), Donnellan et al. (2006, p. x), Chopra and Meindl (2007, pp. 188f.), Simchi-Levi et al. (2008, pp. 190, 194, 345), Shah (2009, p. 166), Bretzke (2010, pp. 77f.), Schuckel (2010, p. 152).

<sup>81</sup> Bretzke (2010, pp. 77f.).

<sup>82</sup> Lee (1996), Aviv and Federgruen (2001b, p. 579).

<sup>83</sup> Yang and Schrage (2009, p. 837).

effect.<sup>84</sup> Postponement is analyzed by Eppen and Schrage (1981) in the steel industry, Heskett and Signorelli (1984) at Benetton, Fisher and Raman (1996) at Sport Obermeyer, Feitzinger and Lee (1997) at Hewlett Packard, Magretta (1998), Van Hoek (1998b), and Kumar and Craig (2007) at Dell, Inc., Van Hoek (1998b) with the SMART car, Battezzati and Magnani (2000) for industrial and fast moving consumer goods in Italy, Brown et al. (2000) at a semiconductor firm, Chiou et al. (2002) in the Taiwanese IT industry, Huang and Lo (2003) in the Taiwanese desktop personal computer industry, Dominguez and Lashkari (2004) at a major household appliance manufacturer in Mexico, Caux et al. (2006) in the aluminum-conversion industry, Davila and Wouters (2007) at a disk drive manufacturer, Cholette (2009) in wine distribution, ElMaraghy and Mahmoudi (2009) in the optimal location of nodes of a global automobile wiper supply chain considering currency exchange rates and the optimal modular product structure, Kumar et al. (2009) at 3M Company, Kumar and Wilson (2009) in off-shored manufacturing, and Wong et al. (2009) in terms of the optimal differentiation point positioning and stocking levels.

(8) Capacity pooling is the consolidation of production,<sup>85</sup> service,<sup>86</sup> transportation,<sup>87</sup> or inventory capacities of several facilities.<sup>88</sup> Without pooling every facility fulfills demand just with its own capacity. With pooling demand is aggregated and fulfilled by the pooled capacity.<sup>89</sup> If demand is stochastic, a higher service level can be attained with the same capacity or the same service level can be offered with less capacity.<sup>90</sup> Capacity pooling may pool supplier lead times, if the capacities receive separate deliveries from the suppliers and provide the whole system with the possibility of partial stock replenishments.<sup>91</sup> However, this is considered under stock sharing (transshipments). Capacity pooling is predominantly associated with combining manufacturing capacity<sup>92</sup> and thus creating manufacturing

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<sup>84</sup> Lee and Tang (1997, p. 52), Aviv and Federgruen (2001a, p. 514, 2001b, p. 579), Alfaro and Corbett (2003, pp. 12, 15), Piontek (2007, p. 87), Dominguez and Lashkari (2004, p. 2113), Anupindi et al. (2006, pp. 192f.), Caux et al. (2006), Jiang et al. (2006), Cholette (2009).

<sup>85</sup> Plambeck and Taylor (2003), Iyer and Jain (2004), Jain (2007), Simchi-Levi et al. (2008, p. 281).

<sup>86</sup> Cachon and Terwiesch (2009, pp. 149ff., 325, 349, 467).

<sup>87</sup> Masters (1980, p. 71), Evers (1994), Ihde (2001, p. 33), Chen and Chen (2003), Chen and Ren (2007).

<sup>88</sup> Anupindi et al. (2006, p. 223), Yu et al. (2008, p. 1), Cachon and Terwiesch (2009, p. 463).

<sup>89</sup> Yu et al. (2008, p. 1).

<sup>90</sup> Anupindi et al. (2006, p. 224), Yu et al. (2008, p. 1).

<sup>91</sup> Cf. Evers (1997, 1999), Wanke and Saliby (2009).

<sup>92</sup> Plambeck and Taylor (2003), Iyer and Jain (2004), Jain (2007), Simchi-Levi et al. (2008, p. 281).

flexibility.<sup>93</sup> This book adopts this view and subsumes pooling of inventory capacity under inventory pooling. Manufacturing flexibility means that a plant is capable of producing more than one product. With no flexibility each plant can only produce one product, with total flexibility every plant can produce every product (as in manufacturing postponement). Flexibility allows production shifts to high selling products to avoid lost sales.<sup>94</sup> Capacity pooling and manufacturing flexibility, e.g., helped American Honda Motor Co., Inc. to gain a competitive advantage in the U.S. when American consumers preferred fuel-efficient cars during the economic downturn. Honda could switch faster from producing bigger cars to building smaller ones. Hiroyuki Yoshino, president of Honda in 2002, even claimed, “We can build any product at any plant at any time, anyplace in the world”.<sup>95</sup>

(9) Product pooling is the unification of several product designs to a single generic or “universal design”<sup>96</sup> or reducing the number of products or stock keeping units (“SKU rationalization”<sup>97</sup>) thereby serving demands that were served by their own product variant before with fewer products.<sup>98</sup> For example, a water pump with integrated coarse thread and O-ring-seal (design with functional integration) could be offered instead of a preassembled water pump with a separate sealing (design without functional integration),<sup>99</sup> and two individual wet suit designs could be combined to a universal design.<sup>100</sup> Stock keeping unit proliferation leads to increasing lead times, costs, and many slow-movers.<sup>101</sup> Therefore Procter & Gamble, e.g., decreased the number of variants of Head & Shoulders dandruff shampoo from 22 to 15<sup>102</sup> and Ford decreased the number of models in its Taurus product line by 30 % from 1988 to 1995.<sup>103</sup> The number of O-ring variants first increased from 1987 to 1996 from 100 to 337 to be then reduced to 85 again in 1997.<sup>104</sup> The demands for the different products are aggregated to the demand for the universal design or the reduced number of SKUs, which fluctuates less thanks to risk-pooling. Product pooling is closely related to postponement,

<sup>93</sup> Upton (1994, 1995), Jordan and Graves (1995), Weng (1998), Pringle (2003), Chopra and Sodhi (2004, p. 59), Goyal et al. (2006), Van Mieghem (2007), Mayne et al. (2008), Cachon and Terwiesch (2009, pp. 344–351).

<sup>94</sup> Cachon and Terwiesch (2009, pp. 344f.).

<sup>95</sup> Mayne et al. (2008).

<sup>96</sup> Cachon and Terwiesch (2009, p. 330).

<sup>97</sup> Jabbonsky (1994), Lahey (1997), Kulpa (2001), Pamplin (2002), Alfaro and Corbett (2003, p. 12), Neale et al. (2003), HTT (2005), Sheffi (2006, p. 119, 2007), Covino (2008), Harper (2008), Sobel (2008, p. 172), Chain Drug Review (2009a, 2009b), Hamstra (2009), MMR (2009), Orgel (2009), Pinto (2009a, 2009b), Ryan (2009), Thayer (2009).

<sup>98</sup> Alfaro and Corbett (2003, p. 12), Cachon and Terwiesch (2009, pp. 330–336, 467).

<sup>99</sup> Thonemann (2010, slides to chap. 8, chart 10).

<sup>100</sup> Cachon and Terwiesch (2013, p. 326f.).

<sup>101</sup> Thonemann and Bradley (2002), Garry (2011, p. 32).

<sup>102</sup> The Financial Times (1998, p. 15), as cited in Thonemann and Bradley (2002, p. 549).

<sup>103</sup> Kelly Blue Book (1988–1995), as cited in Thonemann and Bradley (2002, p. 549).

<sup>104</sup> Thonemann (2010, slides to chap. 8, chart 18).

**Table 2.1** Risk-pooling methods' building blocks

| Building blocks | Risk-pooling methods |    |    |    |    |    |    |    |    |    |
|-----------------|----------------------|----|----|----|----|----|----|----|----|----|
|                 | IP                   | VP | TS | CO | OS | CC | PM | CP | PP | PS |
| DP              | 1                    | 1  | 1  | 1  | 0  | 1  | 1  | 1  | 1  | 1  |
| LP              | 0                    | 0  | 1  | 0  | 1  | 0  | 0  | 0  | 0  | 0  |

where the differentiation of a universal product to individual ones is delayed<sup>105</sup> and to standardization and component commonality. It may, however, prohibit risk-pooling benefits from product substitution.

In (10) product substitution one tries to make customers buy another alternative product, because the original customer wish is out of stock<sup>106</sup> or although it is available (“demand reshape”<sup>107</sup>). Substitution allows the manufacturer, retailer, or service provider to aggregate demand across substitutable components, products,<sup>108</sup> or services (DP<sup>109</sup>).

Table 2.1 summarizes whether the identified risk-pooling methods entail DP and/or LP. It can result in a classification according to the notation DP/LP that indicates which risk-pooling properties the risk-pooling method of concern relies upon. A 1 indicates that the respective property applies, a 0 the contrary. IP, e.g., would be classified as a 1/0—risk-pooling method. This enables to develop, subsume, and analyze further risk-pooling methods under the definition and framework established here.

Both DP and LP reduce variability and thus inventory<sup>110</sup> for a given service level, increase the service level for a given inventory, or achieve a combination of both.<sup>111</sup>

The next section will explain the statistical foundation for both risk-pooling building blocks.

## 2.3 Explaining Risk Pooling

Risk pooling can e.g. be shown for inventory or location pooling: Let  $n$  different locations hold one specific product in inventory.<sup>112</sup> Customer demand  $x_i$  for this product is stochastic and normally distributed with the “mean  $\mu_i$  and standard

<sup>105</sup> Alfaro and Corbett (2003, p. 25).

<sup>106</sup> Swaminathan (2001, p. 130), Chopra and Meindl (2007, pp. 324ff.), Simchi-Levi et al. (2008, p. 348).

<sup>107</sup> Eynan and Fouque (2003, 2005).

<sup>108</sup> Chopra and Meindl (2007, pp. 324ff.).

<sup>109</sup> Ganesh et al. (2008, p. 1124), Yang and Schrage (2009, p. 837).

<sup>110</sup> Cf. Romano (2006, p. 320), Simchi-Levi et al. (2008, p. 48), Cachon and Terwiesch (2009, pp. 325, 350), Bidgoli (2010, p. 209).

<sup>111</sup> Cf. Chopra and Meindl (2007, p. 336), Cachon and Terwiesch (2009, pp. 325, 350).

<sup>112</sup> Gaukler (2007).

deviation  $\sigma_i$ ” for every location  $i = 1, \dots, n$ .<sup>113</sup> The standard deviation  $\sigma_i$  is a measure of dispersion of individual values of the random variable  $x_i$  around the mean  $\mu_i$  for every entity  $i$  and therefore a measure of  $x_i$ ’s variability.<sup>114</sup>

A random variable is a variable that takes its values (realizations) with certain probabilities respectively whose values are assigned to certain probability densities.<sup>115</sup>

If (the empirical distribution of) demand is forecast,<sup>116</sup>  $\sigma_i$  is the standard deviation of the distribution of the forecast error in formula (2.1) for calculating safety stock.<sup>117</sup> An estimate of expected demand (the forecast value) is ordered to satisfy the expected value of demand and safety stock is built up as protection against the forecast error, which is at least as high as the demand variability or standard deviation of demand. Safety stock is not built up as a protection against uncertainty in demand.<sup>118</sup> A high safety stock is needed, if the (standard deviation of the) forecast error is high. The size of demand fluctuations is irrelevant.<sup>119</sup> If the distribution of demand is known,  $\sigma_i$  is the standard deviation of demand<sup>120</sup> and safety stock is held to hedge against uncertainty in demand arising from its variability. The higher the uncertainty in demand, the higher is the safety stock. The standard deviation of demand is zero and no safety stock is needed, if there is no demand uncertainty<sup>121</sup> and no lead-time uncertainty either. Nonetheless, some companies forecast demand, but wrongly use the standard deviation of demand instead of the standard deviation of the forecast error in calculating safety stock.<sup>122</sup> These relationships are also often misconceived in the risk-pooling literature. Therefore they are clarified here.

If every location only fulfills its own customers’ demand, location  $i$  has to carry a level of safety stock which protects it against the uncertainty of  $x_i$ .<sup>123</sup> Let location  $i$ ’s optimal safety stock in accordance with the newsboy model<sup>124</sup> be

$$ss_i = z\sigma_i, \quad (2.1)$$

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<sup>113</sup> Gaukler (2007).

<sup>114</sup> Gravetter and Wallnau (2008, p. 109).

<sup>115</sup> Alisch et al. (2004, p. 3454).

<sup>116</sup> Thonemann (2005, pp. 255f.).

<sup>117</sup> Caron and Marchet (1996, p. 239), Pfohl (2004a, p. 114), Thonemann (2005, pp. 255f.), Chopra and Meindl (2007, p. 306).

<sup>118</sup> Thonemann (2005, pp. 255f.).

<sup>119</sup> Thonemann (2005, p. 257).

<sup>120</sup> Zinn et al. (1989, p. 4).

<sup>121</sup> Thonemann (2005, p. 238).

<sup>122</sup> Korovessi and Linninger (2006, pp. 489f.).

<sup>123</sup> Gaukler (2007).

<sup>124</sup> Cf. e. g. Thonemann (2005, p. 220), Cachon and Terwiesch (2009, p. 235).

where the  $z$  stands for the safety factor that is consistent with a certain target service level. Consequently, the overall safety stock of all locations is<sup>125</sup>

$$ss = z \sum_{i=1}^n \sigma_i. \quad (2.2)$$

If all inventory is carried at one location, this location has to fulfill the entire demand<sup>126</sup>

$$x = \sum_{i=1}^n x_i. \quad (2.3)$$

The individual demands are aggregated across all locations. Safety stock in the centralized system is<sup>127</sup>

$$ss_c = z\sigma_a, \quad (2.4)$$

where<sup>128</sup>

$$\sigma_a = \sqrt{\sum_{i=1}^n (\sigma_i)^2 + 2 \sum_{i=1}^n \sum_{i<j}^n \sigma_i \sigma_j \rho_{ij}} \quad (2.5)$$

is the standard deviation of  $x$  and  $\rho_{ij}$  is the correlation coefficient of the value of the random variable for locations  $i$  and  $j$ .

It can be formally shown that the aggregated variability (standard deviation of total demand  $\sigma_a$ ) is less than or equal to the sum of the individual variabilities (sum of standard deviations of demand at the  $n$  locations  $\sigma$ ) because of “the subadditivity property of the square root” of non-negative real numbers<sup>129</sup>:

$$\sigma = \sum_{i=1}^n \sigma_i \geq \sigma_a = \sqrt{\sum_{i=1}^n (\sigma_i)^2 + 2 \sum_{i=1}^n \sum_{i<j}^n \sigma_i \sigma_j \rho_{ij}}. \quad (2.6)$$

Therefore the safety stock to assure a certain service level in the centralized system is less than or equal to the one in the decentralized system:

$$ss = z \sum_{i=1}^n \sigma_i \geq ss_c = z \sqrt{\sum_{i=1}^n (\sigma_i)^2 + 2 \sum_{i=1}^n \sum_{i<j}^n \sigma_i \sigma_j \rho_{ij}}. \quad (2.7)$$

<sup>125</sup> Gaukler (2007).

<sup>126</sup> Gaukler (2007).

<sup>127</sup> Gaukler (2007).

<sup>128</sup> Cf. Mood et al. (1974, p. 178), Zinn et al. (1989, p. 5), Jorion (2009, p. 43).

<sup>129</sup> Gaukler (2007).

Inequality (2.6) is a special case of the known Minkowski inequality for  $p = 2$ . It is always correct, if the variances exist, therefore also for the Poisson and Binomial distribution.<sup>130</sup>

Hence, the standard deviation of the aggregate demand is lower than or equal to the sum of the standard deviations of the individual demands. Consequently, inventory pooling or centralization at a single location can reduce the amount of safety stock necessary to ensure a given service level in terms of inventory availability. The reduction in safety stock depends on the correlations between  $x_i$ ,  $i = 1, \dots, n$ . Inventory pooling does not always reduce safety stock due to the less-than-or-equal sign. Yet, the sum of the individual variabilities (standard deviations) only equals the total aggregated variability (the square root of the sum of the individual variances plus two times the covariance of the random variable's value for two entities  $i$  and  $j$ ) in two cases:

1. The random variables  $x_i$  are perfectly positively correlated (the coefficient of correlation  $\rho_{ij}$  equals 1,  $\forall i, j$ ):<sup>131</sup>

$$\begin{aligned}\sigma_a &= \sqrt{\sum_{i=1}^n (\sigma_i)^2 + 2 \sum_{i=1}^n \sum_{i < j}^n \sigma_i \sigma_j \rho_{ij}} = \sqrt{\sum_{i=1}^n \sum_{j=1}^n \sigma_i \sigma_j \rho_{ij}} \\ &= \sqrt{\sum_{i=1}^n \sum_{j=1}^n \sigma_i \sigma_j \cdot 1} = \sqrt{\left(\sum_{i=1}^n \sigma_i\right)^2} = \sum_{i=1}^n \sigma_i = \sigma.\end{aligned}\quad (2.8)$$

2. Random variables  $x_i$  cannot mutually balance their fluctuations, if at least  $n - 1$   $\sigma_i$  equal zero: If  $n - 1$   $\sigma_i$  equal zero, (2.6) becomes

$$\sigma = \sigma_i = \sigma_a \quad (2.9)$$

for this single non-zero  $\sigma_i$ . If all  $\sigma_i$  are zero, (2.6) becomes

$$\sigma = 0 = \sigma_a. \quad (2.10)$$

Apart from this, for independent (the correlation coefficient  $\rho_{ij}$  is equal to 0,  $\forall i, j$ ) normally distributed random variables risk pooling leads to variability reduction:

$$\sigma = \sum_{i=1}^n \sigma_i > \sigma_a = \sqrt{\sum_{i=1}^n (\sigma_i)^2}. \quad (2.11)$$

<sup>130</sup> Minkowski (1896), Abramowitz and Stegun (1972, p. 11), Bauer (1974, p. 72), Gradshteyn and Ryzhik (2007, p. 1061).

<sup>131</sup> The expression  $\sqrt{\sum_{i=1}^n \sum_{j=1}^n \sigma_i \sigma_j \rho_{ij}}$  (cf. Moyer et al. 1992, p. 222) in Eq. (2.8) can also be written as  $\sqrt{\sum_{i=1}^n (\sigma_i)^2 + \sum_{i=1}^n \sum_{j=1, j \neq i}^n \sigma_i \sigma_j \rho_{ij}}$  (cf. Jorion 2009, p. 43).

The highest possible variability reduction is achieved, if there are negative correlations which make the second term under the square root equal to minus the first term<sup>132</sup> in Eq. (2.6).

Thus the benefit of risk pooling generally increases with decreasing correlation of pooled demands and/or lead times and concentration of uncertainty (decreasing heterogeneity of the standard deviations of the demands) as well as increasing variability. Risk pooling usually shows increasing returns, but diminishing marginal returns, so that the main benefit can be gained by partly application and complete application might not be necessary or cost efficient.<sup>133</sup>

Some authors<sup>134</sup> give the impression that risk pooling always reduces total variability or enables to reduce inventory, although this must not be the case as shown above.

Likewise industry and academia often assume that inventory pooling, one risk-pooling method, was always beneficial, i.e. that it either reduced costs or increased profits, and that the value of inventory pooling increased with increasing variability of demand.<sup>135</sup> Kemahlioğlu-Ziya (2004, p. 40) states this was only always correct for normally distributed demand such as in Eppen (1979) or Eppen and Schrage (1981). She neglects though that this is not correct for perfectly positively correlated demands and if at least  $n - 1$   $\sigma_i$  equal zero.

Furthermore, for uncertain demand and certain conditions more risk pooling or willingness to substitute may not lead to higher expected profits or “lower optimal total inventory”<sup>136</sup> (“inventory anomaly”) for full<sup>137</sup> and partial substitution or risk pooling.<sup>138</sup>

Inventory pooling may reduce costs and increase profits for the supply chain party holding inventory,<sup>139</sup> but may reduce the total supply chain profits. In a two-echelon supply chain, where the upper echelon (the supplier) carries inventory, the lower echelon (the retailers), whose revenues depend only on sales, may lose profits due to pooling.<sup>140</sup> The supplier and the retailers are likely to benefit from risk-pooling inventory, if the stockout penalty cost is high.<sup>141</sup>

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<sup>132</sup> Cf. Eppen (1979, p. 500).

<sup>133</sup> Oeser (2011, pp. 19ff.).

<sup>134</sup> Tallon (1993, p. 186), Anupindi et al. (2006, p. 191), Gaukler (2007), Ganesh et al. (2008, p. 1134), Pishchulov (2008, p. 8), Romano (2006, p. 320), Simchi-Levi et al. (2008, p. 48, 50f.). For further information please refer to Oeser (2011, p. 17).

<sup>135</sup> Kemahlioğlu-Ziya (2004, p. 40).

<sup>136</sup> Yang and Schrage (2009, p. 837).

<sup>137</sup> Baker et al. (1986), Pasternack and Drezner (1991), Gerchak and Mossman (1992).

<sup>138</sup> McGillivray and Silver (1978), Parlar and Goyal (1984), Anupindi and Bassok (1999), Ernst and Kouvelis (1999), Rajaram and Tang (2001), Netessine and Rudi (2003).

<sup>139</sup> Kemahlioğlu-Ziya (2004), Bartholdi and Kemahlioğlu-Ziya (2005).

<sup>140</sup> Anupindi and Bassok (1999).

<sup>141</sup> Dai et al. (2008, p. 411).

Nonetheless, even decentralized competing retailers selling the same product usually are better off (increase their expected sales) by transshipping under optimal policies compared to no inventory sharing, especially smaller and geographically distant retailers.<sup>142</sup>

The normal random variable  $x_i$  in the given derivation of risk pooling can also be the demands for  $i$  unique components, product versions, substitute products, customized products, or (replenishment) lead times to  $i$  locations. They are aggregated to the demand for a common component in component commonality,<sup>143</sup> universal product in product pooling, all substitutes in product substitution or demand reshape, the undifferentiated generic product in postponement or delayed product differentiation, or to an aggregated lead time across all locations, suppliers, or deliveries in lead-time pooling (emergency transshipments and order splitting). The aggregated demand and/or lead time  $x$  may fluctuate less, as the stochastic fluctuations ( $\sigma_i$ ) of the individual demands and/or lead times usually balance each other to a certain extent (Eq. (2.6)).

Risk pooling by demand pooling in transshipments, virtual pooling, centralized ordering, and capacity pooling can be derived in the same manner as shown for inventory pooling: Demands are pooled across locations.

After clarity about risk pooling has been established it is now placed in the supply chain, business logistics, and a value chain to facilitate its analysis.

## 2.4 Placing Risk Pooling in the Supply Chain, Business Logistics, and a Value Chain

Business logistics (management) is difficult to distinguish from supply chain management (SCM). The terms are often used synonymously, although logistics is majorly seen as a part of SCM and not vice versa as in earlier literature.<sup>144</sup> According to Kotzab (2000) the German business logistics conception already comprised a holistic management along the whole value creation chain before it adopted the English term SCM. Gabler's business encyclopedia defines SCM as building and administrating integrated logistics chains (material and information flows) from raw materials production via processing to end consumers.<sup>145</sup> This book uses the terms business logistics and logistics synonymously. The term business logistics highlights logistics as a business concept.

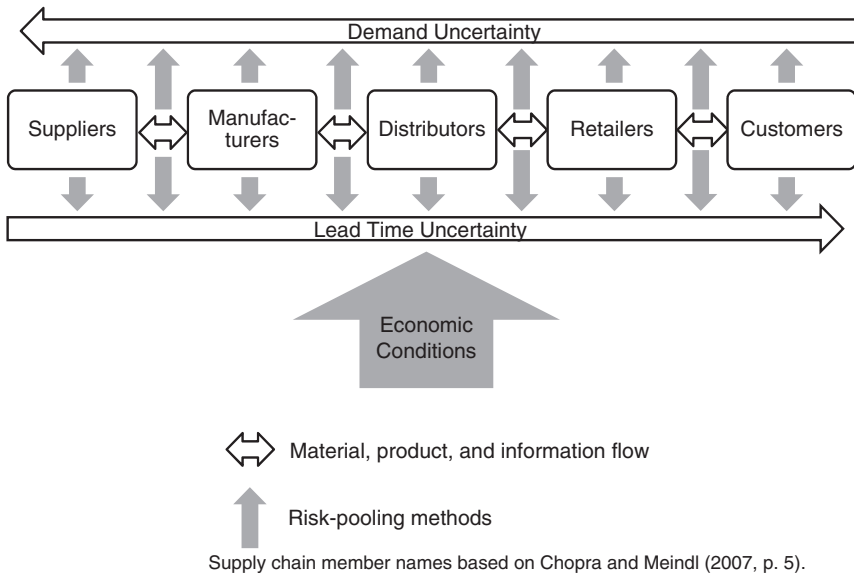
Business logistics comprises the holistic, market-conform, and efficient planning, organization, handling, and control of all material, product, and information

<sup>142</sup> Çömez et al. (2012a, p. 290).

<sup>143</sup> Dogramaci (1979, p. 130).

<sup>144</sup> Ballou (2004b, pp. 4, 6f.), Larson and Halldórsson (2004), CSCMP (2010).

<sup>145</sup> Alisch et al. (2004, p. 2870).



**Fig. 2.2** Placing risk pooling in business logistics

flows from the supplier to the company, within the company, and from the company to the customer<sup>146</sup> and back (reverse logistics).<sup>147</sup>

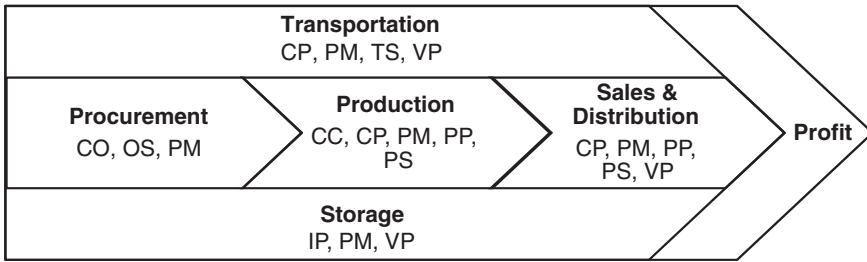
As Fig. 2.2 shows, the efficient and effective material, product, and information flow is impaired by, inter alia, demand and lead-time uncertainty. Risk-pooling methods can mitigate these uncertainties. In the author's opinion, all mentioned risk-pooling methods but order splitting can reduce demand uncertainty, order splitting only lead time uncertainty,<sup>148</sup> component commonality, capacity pooling, inventory pooling, product pooling, and product substitution only demand uncertainty. Transshipments and virtual pooling, postponement, and centralized ordering may dampen both uncertainties. Concerning order splitting and component commonality there are dissenting individual opinions, which are discussed in detail in Oeser (2011, pp. 60f.). Various economic conditions have been found to favor the different risk-pooling methods, which form the basis for the contingency approach used in developing the decision support tool for choosing suitable risk-pooling methods in Sect. 3.2.

The identified risk-pooling methods can be implemented at or between the various supply chain members (suppliers, manufacturers, wholesalers, distribution

<sup>146</sup> Wegner (1996, pp. 8f.).

<sup>147</sup> See e.g. Richter (1996a, b, 1997), Richter and Dobos (1999, 2003a, b), Dobos and Richter (2000), Richter and Sombrutski (2000), Richter and Weber (2001), Richter and Gobsch (2005), Gobsch (2007).

<sup>148</sup> Evers (1999, p. 123), Wanke and Saliby (2009, p. 679).



**Fig. 2.3** Important value activities using risk-pooling methods

centers, central warehouses, delivery or regional warehouses, retailers, stores, and customers). Component commonality rather concerns production. In general capacity and inventory pooling and postponement may pool inventories or capacities of or for different locations. Component commonality, postponement, product pooling, and product substitution may refer to products or their components. Transshipments and virtual pooling deal with product, material, and information flows between supply chain members within an echelon or across echelons, and centralized ordering and order splitting with procurement between supply chain members.

Logistics may be considered as a cross-organizational (Fig. 2.2) and at every member of the above supply chain a cross-departmental coordination function across all divisions, especially storage, transportation, procurement, production of goods and services (including R&D, recycling, and remanufacturing), and sales and distribution (including order processing, recovery, return, and disposal)<sup>149</sup> in the value chain in Fig. 2.3.

The value chain is a management concept that was developed by Porter (1985, pp. 33ff.) and describes a company as a collection of activities. These activities create value, use resources, and are linked in processes. In our value chain, the main value activities are procurement, production, and sales and distribution, which are supported by the value activities transportation and storage. Value activities are “technologically and economically distinct activities [... a company] performs to do business”.<sup>150</sup>

A value chain oriented classification of the risk-pooling methods enables assessing the complex application of risk-pooling methods. “[R]isk pooling is often central to many recent operational innovations and strategies”<sup>151</sup> and is also subsumed under “Operational Hedging”.<sup>152</sup> Therefore, the risk-pooling methods lend themselves to be considered within these operations or value activities that they affect and risk-pooling research can be fruitfully structured according to the

<sup>149</sup> Delfmann (2000, pp. 323f.), Ballou (2004b, pp. 9ff., 27, 29), Kuhlmann and Matyas (2005, pp. 659f.), Grün et al. (2009, pp. 15, 305), Wannewetsch (2009, pp. 21f.).

<sup>150</sup> Porter (2008, p. 75).

<sup>151</sup> Cachon and Terwiesch (2009, p. 350).

<sup>152</sup> Boyabatli and Toktay (2004), Van Mieghem (2008, pp. 313–350).

value chain approach. “Activities provide the bridge between strategy and implementation”.<sup>153</sup> The implementation of risk-pooling methods still seems to trouble companies as a survey conducted among 102 German manufacturing and trading companies shows.<sup>154</sup> The value chain approach is applied frequently<sup>155</sup> in strategic organizational planning, enables a strategic and holistic cost (activity-based costing) and competition analysis and forms the basis of quality management norm ISO 9001 and the Supply Chain Council’s Supply Chain Operations Reference Model. Thus, risk pooling can be integrated easily here. Finally, the value chain framework and risk pooling pursue the same goal: Enhancing value creation or service level and minimizing costs.

Inventory pooling (IP) mainly pertains to storage, virtual pooling (VP) to dropshipping and cross-filling and transshipments (TS) to transportation, centralized ordering (CO) and order splitting (OS) to procurement, capacity pooling (CP), component commonality (CC), and (form) postponement (PM) to production, and product pooling (PP) and product substitution (PS) to sales. However, VP, extending a location’s inventories to other locations’ ones, is also related to storage and sales. Also transportation and sales or service capacities may be pooled, any logistics decision may be postponed. PP and PS may be applied in production as well. This not mutually exclusive and exhaustive classification of risk-pooling methods according to value activities is reflected in Fig. 2.3 and shows the versatility of risk pooling in tackling demand and lead-time uncertainty.

Risk pooling helps a company to cope with demand and/or lead-time uncertainty and thus to carry out these value activities at a lower cost for a given service level, a higher service level for a given cost, or a combination of both.<sup>156</sup> Thus it may increase expected profit by reducing expected costs and/or increasing expected revenue. Instead of profit Porter’s (1985, p. 38) value chain considers margin, which “is the difference between total value and the collective cost of performing the value activities”.

Risk pooling may allow a company to win a competitive advantage over its competitors by effectively combining Porter’s (2008, p. 75) competition strategies of differentiation and cost leadership, e.g. in mass customization enabled by postponement.<sup>157</sup>

After showing where and how risk pooling can be applied in the supply chain, business logistics, and a value chain, Chap. 3 will now help choosing suitable risk-pooling methods for certain economic conditions based on a contingency approach.

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<sup>153</sup> Porter (1998, p. xviii).

<sup>154</sup> Oeser (2011, pp. 134ff.).

<sup>155</sup> Al Ghamdi (2005).

<sup>156</sup> Chopra and Meindl (2007, p. 336), Cachon and Terwiesch (2009, pp. 325, 350).

<sup>157</sup> For example Feitzinger and Lee (1997).

Risk-Pooling Essentials

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