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| Types of data | Categories of data | Examples |
| Data of customers | Customers’ demography | 78% of customers’ ages are between 22 and 38; 62% of customers live in apartment; 71% of customers are single, etc. |
| Customers’ preferences | 53% of customers prefer the sweep-mop integrated RVC; 81% of customers prefer round shape; 58% of customers prefer grey, black or white colours, etc. |
| Customers’ purchase history | 37% of customers bought air humidifier; 73% of customers checked handheld vacuum cleaner as well; 26% of customers also searched fragrance, etc. |
| Data of concepts | Capability of DPs | The nominated airflow provided by motor is 65 CFM; The filtration system traps 99.9% of particles; The dirt cup capacity is 0.45L, etc. |
| Popularity of DPs | 71% of customers use auto-scheduled cleaning; 68% of customers download the dedicated App; 51% of customers use virtual walls, etc. |
| Dimensions of geometric design | The diameter of RVC is 354 mm; The height of RVC is 105 mm; The diameter of brush is 83 mm, etc. |
| Data of verifications | Outcomes of physical tests | The noise generate by airflow in wind tunnel is 42 dB; The elasticity (tensile modulus) of RVC shield is 3.17GPa; The brake distance of RVC is 24-27 mm, etc. |
| Outcomes of virtual simulations | Battery volume is expected to shrink 30% in 5 years; Cleaning of 180m2 is expected to be finished in 130 min; The brush is expected to cover 97% of dirt, etc. |
| Market feedbacks | 32% of customers mention that battery can only support 2 h cleaning; 61% of customers mention that RVC is not satisfying when cleaning leaves; 18% of customers mention that the dedicated App is sometimes lagging, etc. |
| Data of peer products | Data of functions | 25% of RVCs can mop the floor after sweeping; 80% of handheld vacuum cleaners stir debris in dirt cup; Smart home control hub support voice recognition no less than 30 dB, etc. |
| Data of DPs | 31% of smart home products carry wifi6 network card whilst the rest carry wifi5; The nominated airflow of handheld vacuum cleaner of the same price is 80-90CFM; 70% of RVCs are under 7 kg, etc. |
| Market performance | 65% of flagship RVCs of different brands are priced between $980-$1060; Brand A occupies 21% of RVC market share; Brand C has the highest customers’ satisfaction rate in the previous year, etc. |

Demographic characteristics of customers represent an invaluable source of data for CN generation. There are many ways in which customer demographic data is collected via online platforms. For example, as RVCs are often sold via online platforms, customer data relating to gender, age, and location are recorded during the online buying process. Furthermore, users allow the online platform to access their HTTP cookies for better service, containing their purchase history and browsing data. Another unique data source comes from customer memberships to RVC brands, where customers are required to share demographic information to join. The convergence of a wide range of customer demographic data sources produces valuable insights which designers use for decision-making. For example, an insight such as ’71% of customers have more than one smart home products such as smart home controller, smart music players, and smart air-conditioners’, suggests most RVC customers have a range of informed experiences in smart home products. Another insight, such as ’62% of customers are aged between 23 and 31’, indicates that the main customer demographic is young, which may mean they have a limited financial capacity and that RVC costs should be minimized. As most RVCs are sold online, data of customers’ voices on the online platform is useful for interpreting CNs. Consider the following example of an online review left by Customer A. ‘During set up of the phone app which is the centre of all the smart features. You are required to set up an account. You next are required to provide your home router password to the phone app so that the robot will be allowed to connect. The app also requires the location in the phone to be turned on. Giving this permission the app connects with the robot and I can start using it. Removing the permission crashes the app and losses the robot’. If this post received + 1000 likes with an 83% support rate, suggesting many people have this problem, it draws attention to the fact that 7% of all complaints are about this particular problem. Therefore, the convenience of using the App is identified as an issue that needs to be optimized. A CN can be formulated as ‘CN1: Customers require an App with convenient usage and simple permission system’. Meanwhile, Customer B and C comments, respectively: ‘I am really happy that I only need to clean up the dust bag once a week. Every Monday I clean it up then that boy knows what it needs to do’. ‘Beware of this junk. Since I used it, it either stops with 30% of the house left due to its full dust bag or gets stuck by hairs and furs’. Both posts receive + 300 likes with a 50% supportive rate, however, each post contradicts the other. By delving into each customer’s demographic data, designers find that Customer B is a male mining engineer who rents a small apartment and stays at home only during the weekend. His RVC cleans up four times a week, with little dust collected each time. Conversely, Customer C is a housewife who lives in a house and owns 2 children, 2 cats, and 1 dog. Her family members often bring debris into the house, and her pets shed hairs constantly. Therefore, her RVC cannot clean up all debris and hairs in one run, especially considering the large size of her house. Moreover, data shows that 26% of customers have troubles with dust bag’s size. Amongst those customers, 64% have huge room space, 37% have more than 4 family members and 71% have one or more pets. Thus, designers can conclude a CN as ‘CN2: Customers have strong demands towards larger dust bags’. Data from customer reviews are an excellent source of CNs. Customer B’s comments and demography show that an RVC to clean itself automatically is important for him. If designers find that 27% customers’ comments are related to the automatic cleaning function, a CN can be formulated as ‘CN3: Customers need the automatic cleaning of RVC’. Meanwhile, Customer C’s comment indicates that her dropped hairs often impede the movement of the RVC. If designers then find that 51% of customers are female and 38% have pets, a CN can be created as ‘CN4:RVC should ensure smooth cleaning and prohibit being stuck by debris’. Designers then also refer to customer voice and product data for the formulation of RVC FRs. For example, in terms of ‘CN4: RVC should ensure smooth cleaning and prohibit being stuck by debris’, data helps designers investigate what FRs can satisfy this CN. By investigating customer voice data, designers find that 31% of complaints are about the stuck filter web in the dust bag, 26% are about the stuck wind tunnel, and the rest 43% are about the stuck wind nozzle. An investigation of physical tests and work monitoring reveals that 24% of stuck cases are caused by large debris like leaves and foams whilst the rest 76% are about flocculent or lumpy debris such as wool or hair. As a result, designers notice that splitting debris after collection is the key to avoid debris getting stuck. The formulation of two FRs is then possible: ’Stir debris during storage’ and ’Split debris during transferring’. Also, designers can also extract FRs from peer products. For example, data show that all RVCs in the market can return to charge after cleaning, then FRs of ’Dock with the home base’ and ’Manage the cleaning path automatically’ can be formulated. Figure 4 shows one example of an RVC’s functional hierarchy. Using data from customer voices and product operation, designers assign target values for each FR. The IDEF0 model is beneficial for collaborating data with FRs. IDEF0 presents a substance conversion to represent an FR [6]. Data quantifies input substances and output substances in this conversion, so FR’s required performance can be calculated. Figure 5 shows IDEF0 models of FR1.3 (Convert electrical power to kinematic power) and FR2.1 (Vacuum debris on the floor) in Fig. 4. In terms of FR1.3, assume design constraints require that the battery of RVC is 14.8 V and 2000 mA (29.6 W), the RVC is 3.8 kg and constantly moves at 0.4 m/s. FR1.3 should provide the power to drive RVC on different materials of floors. Hypothetically, the smooth wood floor’s dynamic coefficient is 0.2 whilst that of rough carpet is 0.63. Then, the power required to maintain that speed is 7.46 and 23.48 W. Thus, FR1.3 can be specified as ‘convert 29.6 W electrical power to kinematic power between 7.46 and 23.48 W’. In termsofFR2.1, assume design constraints require that the maximum airflow speed allowed is 0.042m3/s. Knowing the air density under standard atmosphere pressure is 1.225 kg/m3, drag coefficient is 0.217, and area of nozzle surface is 1.26 × 10−9m2, it then can be calculated that the power required to vacuum is 5.71 W. The efficiency of power transferring is assumed to be 35–45%, the power required can then be calculated as 12.69–16.31 W. Therefore, FR2.1 can be specified as ’vacuum debris on the floor with 12.69–16.31 W power output’. It should be noted that some of these data are the hypothesis for the illustration and may not represent the real work of RV C . 