How High Should We Go? Determining Reservation Values to Negotiate Successfully for Composite Software Services

Online Appendix A. Properties of Solutions

Because of the myriad different composition structures that may be encountered in practice, it is not possible to obtain closed-form solutions in general – this is because there is no closed-form solution for a general linear programming problem (Padberg 1999). However, we are able to show that closed-form solutions may be obtained under some specific conditions. These conditions and associated findings are summarized in the following propositions.

We show in Proposition 1, for any general structure, the closed-form solution for an attribute whose aggregation function is minimization. We denote the optimal solution for attribute *k* and provider *i* as $q_{i,k}^{reserved*}$.

Proposition 1. For any general structure, if attribute *k*'s aggregation function is minimization, $q_{i,k}^{reserved*} = c_k$ provided that $q_{i,k}^{min} \leq c_k \leq q_{i,k}^{max}$.

Proof: Since the aggregation function for attribute *k* is minimization, attribute *k* must be a positive attribute for the service user, a negative attribute for the providers, and the corresponding global constraint is $q_{CS,k}^{reserved} \geq c_k$. Thus, we should guarantee $q_{ER_l,k}^{reserved} \geq c_k$ for $l=1,\ldots L$. Given $q_{ER_l,k}^{reserved} = \min_{s_i \in ER_l} q_{i,k}^{reserved}$, we get $q_{i,k}^{reserved} \geq c_k \; \forall \, i$.

When the broker has no information about provider *i*'s preference, we have $Pref\left(q_{i,k}^{list}, q_{i,k}^{reserved}\right) = 1 - \frac{q_{i,k}^{reserved} - q_{i,k}^{list}}{q_{i,k}^{max} - q_{i,k}^{min}}$. Since attribute *k* is negative for the providers, $Pref\left(q_{i,k}^{list}, q_{i,k}^{reserved}\right)$ is maximized when $q_{i,k}^{reserved} = c_k \; \forall \, i$.

When the broker has information about provider *i*'s preference, we have $Pref\left(o_i^{list}, o_i^{reserved}\right) = \sum_{j=1}^{m} w_{i,j} * Pref\left(q_{i,j}^{list}, q_{i,j}^{reserved}\right)$. Suppose $q_{i,j}^{reserved}$ ($j=1,\ldots, m$) is the solution that optimizes $Pref\left(o_i^{list}, o_i^{reserved}\right)$ and satisfies $q_{i,k}^{reserved} > c_k$ for attribute *k* whose aggregation function is minimization. We can find another set of reservation values $q_{i,j}^{reserved\prime}$ such that $q_{i,k}^{reserved\prime} = c_k$ for attribute k, $q_{i,j}^{reserved\prime}=q_{i,j}^{reserved}$ for $j \neq k$. The contribution to $Pref\left(o_i^{list}, o_i^{reserved}\right)$ from attribute k is greater from $q_{i,k}^{reserved\prime}$ than from $q_{i,k}^{reserved}$, therefore $Pref\left(o_i^{list}, o_i^{reserved\prime}\right) > Pref\left(o_i^{list}, o_i^{reserved}\right)$. This contradicts the assumption that $Pref\left(o_i^{list}, o_i^{reserved}\right)$ is optimal. Thus, $q_{i,k}^{reserved*} = c_k \ \forall \ i$. ■

Proposition 1 shows that for attributes whose aggregation functions are minimization, the best reservation value for each component is the global constraint itself regardless of the composition structure or whether the providers' preferences are known to the broker. Proposition 1 is also applicable to an attribute with a maximization aggregation function because such an attribute can be converted into an attribute with a minimization aggregation function by using the negation of that attribute value.

Next, we show the conditions under which closed-form solutions can be obtained for strictly sequential structures when the broker does not know the providers' preferences and an attribute has either a summation or a multiplication aggregation function. As before, we denote the optimal solution for attribute k and provider i by $q_{i,k}^{reserved*}$. Further, we denote the corresponding objective function value for problem P2 as β_k^*.

Proposition 2a. For strictly sequential structures where the broker does not know any provider's preference and an attribute's aggregation function is summation, $q_{i,k}^{reserved*} = q_{i,k}^{list} - \frac{q_{i,k}^{max} - q_{i,k}^{min}}{\sum_{i=1}^{n}(q_{i,k}^{max} - q_{i,k}^{min})} * \left(\sum_{i=1}^{n} q_{i,k}^{list} - c_k\right)$ provided that $q_{i,k}^{min} \leq q_{i,k}^{list} - \frac{q_{i,k}^{max} - q_{i,k}^{min}}{\sum_{i=1}^{n}(q_{i,k}^{max} - q_{i,k}^{min})} * \left(\sum_{i=1}^{n} q_{i,k}^{list} - c_k\right) \leq q_{i,k}^{max}$.

Proof: The proof is by contradiction. Let $q_{i,k}^{reserved\prime} = q_{i,k}^{list} - \frac{q_{i,k}^{max} - q_{i,k}^{min}}{\sum_{i=1}^{n}(q_{i,k}^{max} - q_{i,k}^{min})} * \left(\sum_{i=1}^{n} q_{i,k}^{list} - c_k\right)$ not be optimal.

(i) We first show that $\beta_k^* \leq 1 - \frac{\sum_{i=1}^{n} q_{i,k}^{list} - c_k}{\sum_{i=1}^{n}(q_{i,k}^{max} - q_{i,k}^{min})}$. Since $\beta_k^* = \min_{i=1,..,n}\{Pref\left(q_{i,k}^{list}, q_{i,k}^{reserved*}\right)\}$, from equation (5) we get $1 - \frac{q_{i,k}^{list} - q_{i,k}^{reserved*}}{q_{i,k}^{max} - q_{i,k}^{min}} \geq \beta_k^*$ and thus $q_{i,k}^{reserved*} \geq q_{i,k}^{list} - (1 - \beta_k^*) * (q_{i,k}^{max} - q_{i,k}^{min})$. Furthermore, $\sum_{i=1}^{n} q_{i,k}^{reserved*} \leq c_k$, so we get $\sum_{i=1}^{n} q_{i,k}^{list} - (1 - \beta_k^*) * \sum_{i=1}^{n}(q_{i,k}^{max} - q_{i,k}^{min}) \leq c_k$. Thus, $\beta_k^* \leq 1 - \frac{\sum_{i=1}^{n} q_{i,k}^{list} - c_k}{\sum_{i=1}^{n}(q_{i,k}^{max} - q_{i,k}^{min})}$.

(ii) We next show that $q_{i,k}^{reserved\prime}$ is feasible ∀ *i*. From the condition specified in the proposition, $q_{i,k}^{min} \le q_{i,k}^{reserved\prime} \le q_{i,k}^{max}$. Moreover, $\sum_{i=1}^{n} q_{i,k}^{reserved\prime} = \sum_{i=1}^{n}(q_{i,k}^{list} - \frac{q_{i,k}^{max}-q_{i,k}^{min}}{\sum_{i=1}^{n}(q_{i,k}^{max}-q_{i,k}^{min})} * (\sum_{i=1}^{n} q_{i,k}^{list} - c_k)) = c_k$. Therefore, $q_{i,k}^{reserved\prime}$ is feasible.

(iii) Let $\beta_k' = \min_{i=1,..,n}\{Pref(q_{i,k}^{list}, q_{i,k}^{reserved\prime})\}$. If it is not optimal, we have $\beta_k' < \beta_k^*$. Since $q_{i,k}^{reserved\prime} = q_{i,k}^{list} - \frac{q_{i,k}^{max}-q_{i,k}^{min}}{\sum_{i=1}^{n}(q_{i,k}^{max}-q_{i,k}^{min})} * (\sum_{i=1}^{n} q_{i,k}^{list} - c_k)$, $Pref(q_{i,k}^{list}, q_{i,k}^{reserved\prime}) = 1 - \frac{q_{i,k}^{list}-q_{i,k}^{reserved\prime}}{q_{i,k}^{max}-q_{i,k}^{min}} = 1 - \frac{\sum_{i=1}^{n} q_{i,k}^{list} - c_k}{\sum_{i=1}^{n}(q_{i,k}^{max}-q_{i,k}^{min})}$ ∀ *i*. Since the preferabilities are identical for all *i*, it then follows that $\beta_k' = \min_{i=1,\ldots,n}\{Pref(q_{i,k}^{list}, q_{i,k}^{reserved\prime})\} = 1 - \frac{\sum_{i=1}^{n} q_{i,k}^{list} - c_k}{\sum_{i=1}^{n}(q_{i,k}^{max}-q_{i,k}^{min})}$. From part (i), $\beta_k^* \le 1 - \frac{\sum_{i=1}^{n} q_{i,k}^{list} - c_k}{\sum_{i=1}^{n}(q_{i,k}^{max}-q_{i,k}^{min})}$, and we get $\beta_k' \ge \beta_k^*$ which contradicts $\beta_k' < \beta_k^*$. ■

We note that since $q_{CS,k}^{reserved*} = \sum_{i=1}^{n} q_{i,k}^{reserved*} = c_k$, the global constraint is binding and thus the above solution is also a closed-form solution for problem P1 (Section 4.5).

Proposition 2b. For strictly sequential structures where the broker does not know any provider's preference and an attribute's aggregation function is multiplication, the optimal solution is one where $\ln(q_{i,k}^{reserved}) = \ln(q_{i,k}^{list}) - \frac{\ln(q_{i,k}^{max})-\ln(q_{i,k}^{min})}{\sum_{i=1}^{n}(\ln(q_{i,k}^{max})-\ln(q_{i,k}^{min}))} * (\sum_{i=1}^{n}\ln(q_{i,k}^{list}) - \ln(c_k))$ provided that $\ln(q_{i,k}^{min}) \le \ln(q_{i,k}^{list}) - \frac{\ln(q_{i,k}^{max})-\ln(q_{i,k}^{min})}{\sum_{i=1}^{n}(\ln(q_{i,k}^{max})-\ln(q_{i,k}^{min}))} * (\sum_{i=1}^{n}\ln(q_{i,k}^{list}) - \ln(c_k)) \le \ln(q_{i,k}^{max})$.

Proof: The proof follows from Proposition 2a by making a logarithm transformation for all the variables and constraints. Let $q_{i,k}^{reserved\prime} = \ln(q_{i,k}^{reserved})$, $q_{i,k}^{list\prime} = \ln(q_{i,k}^{list})$, $q_{i,k}^{max\prime} = \ln(q_{i,k}^{max})$, $q_{i,k}^{min\prime} = \ln(q_{i,k}^{min})$, and $c_k' = \ln(c_k)$. Since $\prod_{i=1}^{n} q_{i,k}^{reserved} \le c_k$, we get $\sum_{i=1}^{n} q_{i,k}^{reserved\prime} \le c_k'$. After this transformation, the aggregation function for $q_{i,k}'$ becomes summation, i.e., $q_{cs,k}' = \sum_{i=1}^{n} q_{i,k}'$. The result then follows directly from Proposition 2a. ■

Proposition 2a shows that for a strictly sequential composite structure where the broker has no information about providers' preferences, the optimal reservation values for a QoS attribute that has summation aggregation function can be obtained by first determining the difference between the aggregate of the listed values over the components and the global constraint (i.e., the infeasible amount), and then adjusting that amount from the individual listed values of the component services in a manner proportional to the dispersion (range) of the attribute values of the component services provided the solutions remain feasible. A similar idea, with appropriate log transformation, applies to attributes whose aggregation function is multiplication (Proposition 2b).

We show in Proposition 3 that a closed form solution can exist under certain conditions when the broker knows all providers' preferences (Problem P4) for a strictly sequential composite structure. We observe that, after suitable transformations, the aggregation functions multiplication and maximization can be converted to summation and minimization, respectively. Therefore, for expositional simplicity, we only consider attributes with aggregation function summation (this set is denoted by *A*) and minimization (denoted by *B*).

Proposition 3. For strictly sequential structures where the broker knows all providers' preferences, $q_{i,k}^{reserved*}=q_{i,k}^{list} - \frac{q_{i,k}^{max}-q_{i,k}^{min}}{\sum_{i=1}^{n}(q_{i,k}^{max}-q_{i,k}^{min})} * \left(\sum_{i=1}^{n} q_{i,k}^{list} - c_k\right) \forall k \in A$, if the following conditions are satisfied: 1) for every k, $w_{i,k}$ is equal $\forall$ i; 2) for every k, $q_{i,k}^{max} - q_{i,k}^{min}$ is equal $\forall$ i; 3) when $k \in A$, $q_{i,k}^{min} < q_{i,k}^{list} - \frac{q_{i,k}^{max}-q_{i,k}^{min}}{\sum_{i=1}^{n}(q_{i,k}^{max}-q_{i,k}^{min})} * \left(\sum_{i=1}^{n} q_{i,k}^{list} - c_k\right) < q_{i,k}^{max}$; 4) when $k \in B$, $q_{i,k}^{min} \le c_k \le q_{i,k}^{max}$; and 5) when $k \in B$, $q_{i,k}^{list}$ is equal $\forall$ i.

Proof : Analogous to Proposition 2, the proof is by contradiction. The solution for Problem P4 is denoted by $q_{i,k}^{reserved*}$ with optimal objective function value α^*. Since $q_{i,k}^{min} \le c_k \le q_{i,k}^{max}$, from Proposition 1 we get $q_{i,k}^{reserved*}= c_k \; \forall k \in B$. Assume $q_{i,k}^{reserved\prime}=q_{i,k}^{list}$- $\frac{q_{i,k}^{max}-q_{i,k}^{min}}{\sum_{i=1}^{n}(q_{i,k}^{max}-q_{i,k}^{min})} * \left(\sum_{i=1}^{n} q_{i,k}^{list} - c_k\right)$ for $k \in A$ is not the optimal solution despite $q_{i,k}^{reserved\prime} = c_k$ for $k \in B$.

(i) We first show $\alpha^* \le 1 - \frac{1}{n}\sum_{k\in A}\frac{w_{i,k}}{q_{i,k}^{max}-q_{i,k}^{min}}\left(\sum_{i=1}^{n} q_{i,k}^{list} - c_k\right) - \frac{1}{n}\sum_{k\in B}\frac{w_{i,k}}{q_{i,k}^{max}-q_{i,k}^{min}}\left(\sum_{i=1}^{n} q_{i,k}^{list} - n * c_k\right)$.

Since $\alpha^* = \min_{i=1,..,n}\{Pref(o_i^{list}, o_i^{reserved*})\}$, we get $\alpha^* \le \frac{1}{n}\sum_{i=1}^{n} Pref(o_i^{list}, o_i^{reserved*})$. Now

$Pref\left(o_i^{list}, o_i^{reserved*}\right) = \sum_{k=1}^{m} w_{i,k} * Pref\left(q_{i,k}^{list}, q_{i,k}^{reserved*}\right) = \sum_{k=1}^{m} w_{i,k} * (1 - \frac{q_{i,k}^{list}-q_{i,k}^{reserved*}}{q_{i,k}^{max}-q_{i,k}^{min}}) = 1 - \sum_{k=1}^{m} w_{i,k} * \frac{q_{i,k}^{list}-q_{i,k}^{reserved*}}{q_{i,k}^{max}-q_{i,k}^{min}}$; therefore $\alpha^* \le 1 - \frac{1}{n}\sum_{i=1}^{n}\sum_{k=1}^{m} w_{i,k} * \frac{q_{i,k}^{list}-q_{i,k}^{reserved*}}{q_{i,k}^{max}-q_{i,k}^{min}}$. Given that for every k, $w_{i,k}$ and $q_{i,k}^{max} - q_{i,k}^{min}$ are equal $\forall\ i$, we get $\alpha^* \le 1 - \frac{1}{n}\sum_{k=1}^{m} \frac{w_{i,k}}{q_{i,k}^{max}-q_{i,k}^{min}} (\sum_{i=1}^{n} q_{i,k}^{list} - \sum_{i=1}^{n} q_{i,k}^{reserved*})$ $=1-\frac{1}{n}\sum_{k\in A} \frac{w_{i,k}}{q_{i,k}^{max}-q_{i,k}^{min}} (\sum_{i=1}^{n} q_{i,k}^{list} - \sum_{i=1}^{n} q_{i,k}^{reserved*}) - \frac{1}{n}\sum_{k\in B} \frac{w_{i,k}}{q_{i,k}^{max}-q_{i,k}^{min}} (\sum_{i=1}^{n} q_{i,k}^{list} - \sum_{i=1}^{n} q_{i,k}^{reserved*})$. Furthermore, given $\sum_{i=1}^{n} q_{i,k}^{reserved*} \le c_k$ for attribute $k\in A$ and $q_{i,k}^{reserved*} = c_k$ for attribute $k\in B$, we get $\alpha^* \le 1 - \frac{1}{n}\sum_{k\in A} \frac{w_{i,k}}{q_{i,k}^{max}-q_{i,k}^{min}} (\sum_{i=1}^{n} q_{i,k}^{list} - c_k) - \frac{1}{n}\sum_{k\in B} \frac{w_{i,k}}{q_{i,k}^{max}-q_{i,k}^{min}} (\sum_{i=1}^{n} q_{i,k}^{list} - n * c_k)$.

(ii) We next show that $q_{i,k}^{reserved\prime}$ is feasible. From conditions 3 and 4, we have $q_{i,k}^{min} \le q_{i,k}^{reserved\prime} \le q_{i,k}^{max}$ $\forall$ i, k. Moreover, for $k\in A$, $\sum_{i=1}^{n} q_{i,k}^{reserved\prime} = \sum_{i=1}^{n}(q_{i,k}^{list} - \frac{q_{i,k}^{max}-q_{i,k}^{min}}{\sum_{i=1}^{n}(q_{i,k}^{max}-q_{i,k}^{min})} * \left(\sum_{i=1}^{n} q_{i,k}^{list} - c_k\right)) = c_k$. Similarly, for $k\in B$, we have $q_{i,k}^{reserved\prime} = c_k$ $\forall$ i. Therefore, $q_{i,k}^{reserved\prime}$ is feasible.

(iii) Let $\alpha' = \min_{i=1,..,n}\{Pref\left(o_i^{list}, o_i^{reserved'}\right)\}$. Since $q_{i,k}^{reserved\prime}$ is not the optimal solution, we have $\alpha' < \alpha^*$. Since $q_{i,k}^{reserved\prime} = q_{i,k}^{list} - \frac{q_{i,k}^{max}-q_{i,k}^{min}}{\sum_{i=1}^{n}(q_{i,k}^{max}-q_{i,k}^{min})} * \left(\sum_{i=1}^{n} q_{i,k}^{list} - c_k\right)$ for attribute $k \in A$, and $q_{i,k}^{reserved\prime} = c_k$ for attribute $k\in B$, we have $Pref\left(o_i^{list}, o_i^{reserved\prime}\right) = 1 - \sum_{k=1}^{m} w_{i,k} * \frac{q_{i,k}^{list}-q_{i,k}^{reserved\prime}}{q_{i,k}^{max}-q_{i,k}^{min}} = 1 - \sum_{k\in A} w_{i,k} * \frac{\sum_{i=1}^{n} q_{i,k}^{list} - c_k}{\sum_{i=1}^{n}(q_{i,k}^{max}-q_{i,k}^{min})} - \sum_{k\in B} w_{i,k} * \frac{q_{i,k}^{list}-c_k}{q_{i,k}^{max}-q_{i,k}^{min}}$. Given that $q_{i,k}^{max} - q_{i,k}^{min}$ is equal $\forall i$, and for every $k \in B$ we have $q_{i,k}^{list}$ equal $\forall i$, we have $Pref\left(o_i^{list}, o_i^{reserved\prime}\right)$ identical $\forall i$, where $Pref\left(o_i^{list}, o_i^{reserved\prime}\right) = 1 - \sum_{k\in A} w_{i,k} * \frac{\sum_{i=1}^{n} q_{i,k}^{list} - c_k}{n*(q_{i,k}^{max}-q_{i,k}^{min})} - \sum_{k\in B} w_{i,k} * \frac{n*(q_{i,k}^{list}-c_k)}{n*(q_{i,k}^{max}-q_{i,k}^{min})} =$ 1-$\frac{1}{n}\sum_{k\in A} \frac{w_{i,k}}{q_{i,k}^{max}-q_{i,k}^{min}} (\sum_{i=1}^{n} q_{i,k}^{list} - c_k) - \frac{1}{n}\sum_{k\in B} \frac{w_{i,k}}{q_{i,k}^{max}-q_{i,k}^{min}} (\sum_{i=1}^{n} q_{i,k}^{list} - n * c_k)$. Therefore, $\alpha' = \min_{i=1,..,n}\{Pref\left(o_i^{list}, o_i^{reserved'}\right)\} = 1 - \frac{1}{n}\sum_{k\in A} \frac{w_{i,k}}{q_{i,k}^{max}-q_{i,k}^{min}} (\sum_{i=1}^{n} q_{i,k}^{list} - c_k)$ - $\frac{1}{n}\sum_{k\in B} \frac{w_{i,k}}{q_{i,k}^{max}-q_{i,k}^{min}} (\sum_{i=1}^{n} q_{i,k}^{list} - n * c_k)$, which implies from part (i) that $\alpha^* \le \alpha'$, contradicting the claim

$\alpha' < \alpha^*$. ■

We note that since $q_{CS,k}^{reserved*} = \sum_{i=1}^{n} q_{i,k}^{reserved*} = c_k$ for all attributes $k \in A$ and $q_{CS,k}^{reserved*} = \min_{i=1,..,n} q_{i,k}^{reserved*} = c_k$ for all attributes $k \in B$, all the global constraints are binding and thus it is also a closed-form solution for problem P3 (see Section 4.5).

Interestingly, the results of Proposition 2 are also applicable to a general structure when the aggregation of an attribute in the structure is equivalent to the aggregation of the attribute in a strictly sequential structure. For example, the closed-form solution for the attribute *price* in Example 1 (i.e., problem EP1 in Table 4) can be derived from Proposition 2a because the aggregated price of component services S_1 (transcoding), S_2 (translation), S_3 (merging), and S_4 (compression) is the same regardless of whether the services are executed in sequence or in parallel, and the condition specified in the proposition is satisfied. However, Proposition 2 does not provide the optimal solution for the attribute *response time* in Example 1 (i.e., problem EP2 in Table 4) because, due to the parallel structure, the aggregate function for response time in Example 1 is different from that of a composite service in which S_1, S_2, S_3, and S_4 are executed sequentially. Similarly, Proposition 3 cannot be used to derive the optimal solution for problem EP3 in Table 4.

Online Appendix B--Glossary of Notations

Notation	Meaning
S_i	Component service
CS	The composite service
ER	Execution route
SR	Sub-route
L	Number of execution routes in a composite service
H	Number of sub-routes in a composite service
n	Number of component services in a composite service
m	Number of QoS attributes
c_k	The global constraint for QoS attribute k set by the user
$q_{i,k}$	The value of the kth attribute for component service S_i
$q_{i,k}^{list}$	The value of the kth attribute listed by provider S_i
$q_{i,k}^{reserved}$	The reservation value for QoS attribute k of component service S_i
$q_{i,k}^{\min}$	The minimum value for QoS attribute k of component service S_i
$q_{i,k}^{\max}$	The maximum value for QoS attribute k of component service S_i
$o_i^{reserved}$	The broker's reservation offer for component service S_i
o_i^{list}	The offer listed by provider S_i
$q_{CS,k}^{reserved}$	The reservation value for QoS attribute k of composite service CS
$q_{ER,k}^{reserved}$	The reservation value for QoS attribute k of the execution route ER
$q_{SR,k}^{reserved}$	The reservation value for QoS attribute k of the sub-route SR
$Pref(q_{i,k}^{list}, q_{i,k}^{reserved})$	The preferability of $q_{i,k}^{reserved}$ over $q_{i,k}^{list}$ for QoS attribute k
β_k	The infimum of $Pref(q_{i,k}^{list}, q_{i,k}^{reserved})$ obtained from all the component services
$Pref(o_i^{list}, o_i^{reserved})$	The preferability of $o_i^{reserved}$ over o_i^{list}
α	The infimum of $Pref(o_i^{list}, o_i^{reserved})$ obtained from all the component services
t	The iteration index
$o_{i,t}$	The offer to be proposed by the broker for service S_i at iteration t
$q_{i,k,t}$	The value offered for the QoS attribute k of S_i at iteration t
$U_i^B(t)$	The broker's utility for the component service S_i at iteration t
$U_{i,\max}^B$	The utility of the most aggressive offer the broker B wants to ask from provider i
$U_{i,reserved}^B$	The utility of the broker's reservation offer for component service S_i
$\mu_i^B(t)$	A function which determines the extent of concession at iteration t
$t_{i,\max}^B$	The pre-defined maximum number of iterations for component service S_i
v_i^B	The concavity/convexity coefficient of the concession curve
$U^B(o_{i,t})$	The broker's utility of the offer $o_{i,t}$ for the component service S_i
$U^P(o_{i,t})$	The provider's utility of the offer $o_{i,t}$ for the component service S_i