Chapter 7
The Interaction Effort in Autonomous Logistics Processes: Potential and Limitations for Cooperation

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7.1 Introduction

The complexity, dynamics, and distribution of logistics processes are major challenges for supply network management. The paradigm of autonomous control in logistics [32] addresses these challenges by delegating process control to the participating logistics entities. Autonomous logistics can be implemented with intelligent software agents that represent the logistics objects and act on their behalf [26,30,33]. Decentralising decision-making enables a problem decomposition which, in turn, reduces the computational effort. Every entity has to incorporate only its own parameters plus those of cooperating entities. Simultaneously, occurring dynamics can be dealt with locally.

While problem decomposition reduces the computational effort, another challenge arises: Individual entities can hardly satisfy their objectives on their own. Often, cooperation is necessary. Appropriate organisational structures being established on demand facilitate the required coordination. Simultaneously, organisation can decrease the interaction effort for process control. However, forming these structures and performing activities cooperatively also induces a certain interaction effort. Designers of autonomous logistics processes must trade off both aspects against each other to prevent that the decrease in computational effort is outweighed by the increased interaction effort. This chapter contributes a thorough investigation of the interaction effort for different types of cooperation in autonomous logistics.

The remainder of this chapter is structured as follows: Sect. 7.2 introduces a process that will serve as a recurring example. Based on that foundation, Sect. 7.3 examines the potential for cooperation in autonomous logistics processes. To this end, different types of cooperation are distinguished and analysed. Subsequently, Sects. 7.4 and 7.5 describe how the respective cooperation mechanisms can be implemented. Section 7.6 examines the interaction effort for coordinating autonomous logistics

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entities. A particular focus lies on limitations for cooperation and how they can be dealt with. This helps narrow an appropriate degree [31] for autonomous control in logistics.

7.2 Investigated Process

Onward carriage of sea containers serves as a recurring example throughout the remainder of this chapter. The respective real-world process and its transition to autonomous logistics have been thoroughly investigated [26]. Onward carriage pertains to intermodal transport of sea containers which can be divided into three parts. During pre carriage, the container is transported from the sender to the port of loading. Subsequently, the seaborne transport by container vessel is conducted. The last step is onward carriage from the port of discharge to the receiver of the cargo. The examined real-world process covers two logistics functions, namely transport and storage. The requirements for the logistics objects are as follows:

1. Autonomous shipping containers have to choose a *storage* facility at which their cargo can be received and stored.
2. Autonomous shipping containers have to choose a *transport* service provider for transport to the selected storage facility.

For both tasks, it is necessary to find service providers that are capable of handling the respective cargo. Furthermore, these service providers must have sufficient capacity. Finally, the cheapest matching and available service provider should be chosen. Apart from these criteria for individual objects, additional group-related requirements have to be considered:

1. Similar goods should be stored together in the same storage facility whenever possible.
2. Multiple containers should be transported together on means of mass transport whenever possible.

7.3 Potential for Cooperation in Autonomous Logistics

On the one hand, satisfying Requirements 1 and 2 identified in the preceding section exceeds the capabilities of individual logistics entities. On the other hand, the high degree of spatial distribution of the logistics objects prevents a central entity from taking over coordination tasks [26]. Consequently, autonomous logistics entities must coordinate themselves by establishing adequate organisational structures. Cooperative problem solving [34] can be divided into four steps (Fig. 7.1). Initially, the logistics entities must recognise a potential for cooperation because cooperation is not worthwhile otherwise (Recognition). Having recognised this potential, they

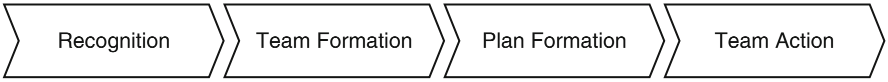

Fig. 7.1 The four steps of the cooperative problem solving process. As a precondition, logistics entities must recognise a potential for cooperation. Subsequently, they form both a team and a joint plan before they actually act jointly

can form teams that are beneficial with regard to their respective goals (Team Formation). Afterwards, the team members agree upon a joint plan (Plan Formation). Finally, the actual execution of the joint plan takes place as the last process step (Team Action). Each of these steps can fail, usually leading to the entities having to return to the preceding step.

The potential for cooperation as a prerequisite for joint action can be identified as follows [34]. Firstly, a logistics entity must recognise that there exists some team of entities that can jointly achieve the intended goal. Secondly, the entity must have a reason for acting in a team. This holds if it cannot achieve its goal in isolation or if there is a goal conflict for all actions it could perform to achieve the goal. In autonomous logistics, the potential for cooperation particularly manifests in the following aspects:

1. Complementing insufficient individual capabilities.
2. Increasing the resource utilisation efficiency.

Sections 7.3.1 and 7.3.2 examine both aspects in more detail with a particular focus on applications in autonomous logistics.

7.3.1 Complementing Insufficient Individual Capabilities

In autonomous logistics, general cargo units are expected to plan and schedule their path through the logistics network themselves. However, these autonomous logistics entities can usually not accomplish their respective tasks on their own. Instead, they have to delegate operations to suitable service providers. As an example from the onward carriage process (Sect. 7.2), an autonomous shipping container cannot move from its source to its sink on its own but has to be transported. Thus, in order to satisfy its objective, the container must be enabled to form a team with one or more means of transport.

Team formation helps autonomous logistics entities complement their insufficient individual capabilities by utilising resources provided by other entities. However, choosing the right partners for cooperation is a difficult task. This choice depends not only on the service type and on spatiotemporal constraints [28], but also on quality criteria like service provider responsiveness and reliability. The former criteria express situational conditions for making a decision. The latter ones describe expectations towards potential cooperation partners and reflect business relationships as well as experience from previous interaction activities.

The dynamics of logistics processes prevent design time evaluation and optimisation of potential cooperations in terms of flexibility and robustness. The following reasons require online formation and adaption of cooperative activities in autonomous logistics:

1. Scheduled operations can fail
2. Demands and capabilities can vary
3. Service providers and consumers can enter and leave the system

The first two reasons lead to the need for replanning and reallocating resources. The third reason is due to the *openness* of such systems [3]. Service providers and consumers entering and leaving the logistics system aggravate the inherent dynamics of logistics processes. They induce further changes in availability, demand, prices, and requirements of products and services.

To summarise, there is a potential for complementing insufficient individual capabilities in autonomous logistics. However, this kind of cooperation cannot be defined at design time but must evolve during runtime. The dynamics of logistics processes evoke the need for each autonomous entity to constantly reconsider and modify its cooperative relationships to other entities in order to effectively reach its objectives.

7.3.2 Increasing the Resource Utilisation Efficiency

Individual autonomous logistics entities can frequently not meet minimum utilisations required by service providers. To reiterate the onward carriage scenario (Sect. 7.2), transport by train is preferable over transport by truck due to lower transport rates. However, the train has a certain minimum utilisation consumers must accept when requesting its service. Transporting an individual container by train alone is thus more expensive than transporting it by truck. Consequently, in autonomous logistics multiple shipping containers can benefit from coordinating themselves for joint resource utilisation.

Figure 7.2 depicts a graph that derives this potential for cooperation analytically. One coordinate axis refers to the number of service providers employed which ranges from 1 to 1,000. The other axis refers to the lot size of each provider, thereby also ranging from 1 to 1,000. The graph depicts the actual overall utilisation induced by 1,000 service consumers, whereby the consumers are assumed to be equally distributed to the service providers.

The graph clearly shows that the need for restricting the number of service providers increases with the lot sizes. If the lot size is 1, it does not make any difference how many service providers are employed. However, with increasing lot sizes also the overall utilisation increases. In case of the lot size being 1,000, the 1,000 service consumers employing 1,000 different providers induce a total utilisation of 1,000,000 although 1,000 would suffice. This means that the higher the lot size of

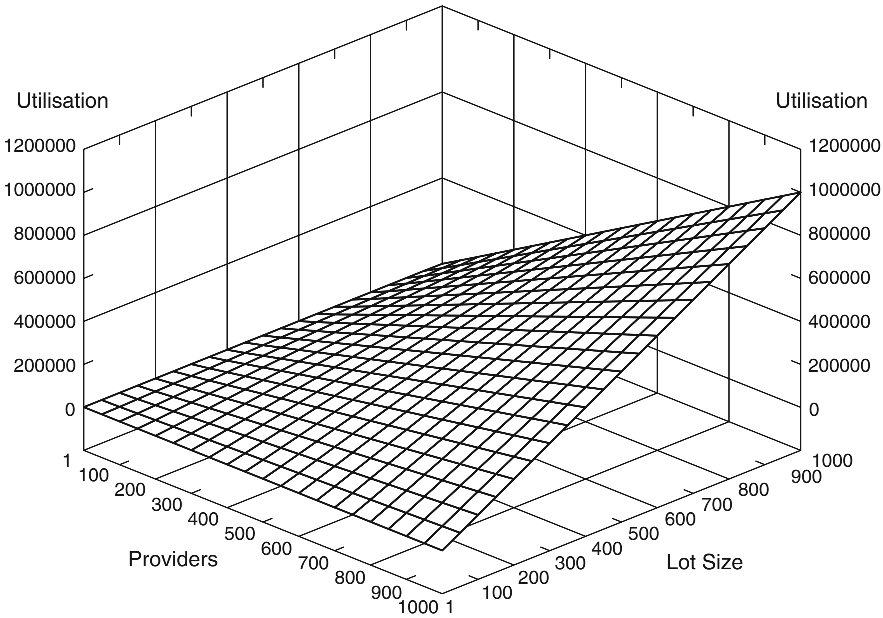

Fig. 7.2 The potential for cooperation of 1, 000 service consumers by joint utilisation of logistics resources. The higher the lot size of the logistics service providers, the higher is the benefit from jointly utilising only a few selected providers

the logistics service providers, the higher is the benefit from jointly utilising only a few selected providers. Hence, there is a massive potential for cooperation.

7.4 Using Resources Effectively

As elaborated in the previous section, finding appropriate cooperation partners that complement own insufficiencies is crucial for effective process control. Section 7.4.1 derives relevant requirements for this task and examines related work. Subsequently, Sect. 7.4.2 describes how effective resource utilisation can be implemented. The particular focus is on how autonomous logistics service consumers can find suitable partners for cooperation among the service providers.

7.4.1 Requirements and Related Work

The logistics domain is shaped by a high degree of both complexity and dynamics and the multiplicity of criteria for the choice of potential cooperation partners

(Sect. 7.3.1). These properties lead to the following requirements for an interaction of autonomous logistics entities facilitating effective resource utilisation:

1. Decentralisation
2. Autonomy
3. Adaptivity
4. Reliability

The demand for choosing suitable cooperation partners in a decentralised way (Requirement 1) is a direct consequence of the decentralised setting in autonomous logistics. Likewise, the autonomy of the logistics entities in their choice of cooperation partners must be preserved (Requirement 2).

In order to enable effective cooperation of these entities, channels and modes for their interaction have to be defined. To this end, a wide variety of different paradigms for interaction structures has been proposed [13], ranging from strict hierarchies [17] to negotiation-based mechanisms [4, 29]. These organisational structures defining the interaction competencies of autonomous entities are chosen at the design stage of a system and thus determine its runtime behaviour. However, cooperation processes must be able to react to changes caused by the dynamics of logistics, i.e., cooperative relationships have to be reconsidered continuously (Requirement 3). Adjusting the patterns of interaction along the spectrum of organisational approaches between delegation and negotiation helps cope with these conditions and attain scalability of cooperation [23, 24]. However, it remains unclear under which conditions which organisational structure is suitable for ensuring effective cooperation.

Not only the dynamics of logistics, but also the capabilities and the behaviour of other entities affect the effectiveness of cooperative activities [19]. This impacts the reliability of the cooperation outcome (Requirement 4). In an open system, the outcome cannot be determined beforehand, but must be assessed from observations during runtime of the system. Based on experience from such observations, it is necessary to model *expectations* concerning the behaviour [3, 18] of other logistics entities that allow for estimating the outcome of cooperative activities.

7.4.2 Emergent Interaction Patterns

Inspired by Luhmann's sociological theory of communication systems [15], feeding the aforementioned expectations back into the decision-making process results in a control loop enabling the emergence of effective cooperation in autonomous logistics [2]. This process consists of three consecutive steps that are executed repeatedly:

1. Estimate the outcome of potential cooperations from past observations.
2. Choose cooperative activities according to the expected results.
3. Memorise actually observed operations outcome.

In this approach, expectations of the results of potential cooperations with other logistics entities are based on the entities storing their observations in a memory.

The outcome of joint activities is therefore estimated using the memory entries describing past observations of similar operations. Choosing its cooperations in accordance with their expected results, an entity will then be able to observe their actual outcome and to store these observations in its memory again. Therewith, the control loop is closed, as the updated memory entries are used to calculate the expected outcome of further activities. Thus, logistics entity relationships emerge from interaction processes while guiding the choice of subsequent operations.

Regarding the properties of the logistics domain, the advantage of these self-organising activity patterns is that the range of potential cooperations can be narrowed to those being expected to have the most promising results. Hence, logistics entities become able to learn best practices in cooperatively utilising resources and capabilities which leads to a gradually increasing performance of the whole system [2]. Moreover, being based on experience, the choice of a logistics service provider as a partner for joint activities not only reflects its reliability according to past observations, but also allows for behavioural adaptions in case of changing conditions: If the actual observations do no longer meet the expected results, the logistics entities will reconsider and adapt their cooperative relationships in order to re-enable effective utilisation of distributed resources.

7.5 Using Resources Efficiently

Joint action has been identified important not only for effective, but also for efficient resource utilisation (Sect. 7.3.2). The required coordination of autonomous logistics entities with similar objectives or properties can be accomplished with respective team formation mechanisms. Section 7.5.1 derives requirements for such mechanisms and examines the applicability of previous approaches. Afterwards, Sect. 7.5.2 describes how team formation for joint resource utilisation can be solved in autonomous logistics.

7.5.1 Requirements and Related Work

Previous work on team formation formalises organisations of autonomous entities [6, 7, 10] as well as the internal states of these entities during team formation [5,34]. By contrast, less effort has been spent on particular interaction protocols for team formation. For the design of such interaction mechanisms, general design principles should be considered [21, 22]. In addition, the intended team formation mechanism for autonomous logistics should meet the following requirements:

1. Decentralisation
2. Genericness
3. No prior knowledge
4. Unique teams
5. Flexible teams

To reiterate the onward carriage process (Sect. 7.2), autonomous control demands that shipping containers with similar properties and objectives act jointly. Team formation of autonomous shipping containers is an inherently distributed problem (Requirement 1). That is, no individual container has a centralised perspective that incorporates all parameters. Consequently, previous cluster algorithms like k-means [16] are not applicable. Approaches to distributed clustering can be found in wireless sensor networks [1]. Usually, these approaches focus on spatial data and make thus implicit assumptions on the environment [11]. This means that they are not applicable for the generic descriptors required in autonomous logistics (Requirement 2). Peer-to-peer approaches [20] do not exhibit this restriction. By contrast, each logistics entity has an arbitrarily chosen set of other entities it is initially connected with. Autonomous entities can then exchange their direct partners by more similar ones. This approach, however, contradicts the requirements that the required prior knowledge should be minimised (Requirement 3). In particular, there is no natural choice for initial peers in autonomous logistics.

A promising candidate for implementing team formation is the contract net [29] interaction protocol. Although it is well-suited for complementing capabilities (Sect. 7.3.1), its applicability to efficient process control is limited. This can be explained as follows: In terms of onward carriage (Sect. 7.2), shipping containers with similar properties and objectives should form one team (Requirement 4). For instance, this means there should only be one team of packages for each pair of origin and destination. Of course, each team of consumers can intentionally employ multiple trucks if necessary. Unique teams ensure the highest utilisation of the logistics resource employed. In other words, the requirement for unique teams means that autonomous logistics entities group themselves by an equivalence relation with respect to one property or a set of properties. Nevertheless, different properties and thus varying teams may exist for different purposes, e.g., transport and storage service allocation. Closely related to unique teams is the requirement for flexible teams (Requirement 5), i.e., members must be able to join after a team has been initially established. With the contract net protocol, team managers would have to continuously advertise their team to potential new members. Despite of efficiency issues, the question remains open what might be an appropriate frequency for such announcements.

7.5.2 Team Formation Interaction Protocol

Team formation for efficient resource utilisation includes the following roles: the initiating participant, already existing team managers, and a directory that administers the list of the current managers.

New entities participating in team formation, initially register themselves as new team managers with the directory service. This behaviour is based on the optimistic assumption that no current team manager matches its properties for team formation. To check whether this assumption is true, all team managers are provided with the properties of the new participant. The list of team managers can be requested from the directory. All communication with the team managers is conducted in parallel. It has three possible results [27]:

1. *No team manager identifies a match*. Then, the optimistic assumption turns out to be right. Consequently, the new participant actually becomes a new team manager.
2. *One team manager determines a match*. Then, the initial assumption was wrong. Consequently, the new participant deregisters from the directory and joins the matching team instead.
3. *Multiple team managers determine a match*. This may happen if multiple logistics entities have concurrently registered with same properties. This can be resolved by assigning an individual registration timestamp to each team manager. Then, all entities including the superfluous team managers can join the initial team.

An alternative approach to optimistic behaviour is conservative interaction as performed in a previous version of the protocol [28]. In that case, new participants first contact all existing team managers before registering themselves with the directory. Still, it cannot be prevented that multiple logistics entities with same properties register as team managers because all entities act concurrently. To resolve this redundancy, all existing team managers must thus be contacted again after the registration process. The optimistic procedure thus has the advantage that team managers only have to be contacted once.

Both approaches have in common that they work in a decentralised way. They make neither special assumptions regarding the team descriptors applied nor special requirements regarding prior knowledge about the system. Furthermore, they enable forming unique and flexible teams as required for efficient resource utilisation.

7.6 Appropriate Degree for Autonomous Control

As an intermediary result, Sects. 7.4 and 7.5 have identified methods for allocating logistics resources with autonomous control both effectively and efficiently. Autonomous logistics is motivated by the decrease in computational effort achieved by problem decomposition. The higher the degree of decentralisation, however, the higher the need for coordination. That is, the interaction effort increases with the number of participating autonomous logistics entities. Therefore, it is important to identify limitations and thereupon an appropriate degree at which autonomous control should be conducted.

Section 7.6.1 examines the interaction effort for complementing insufficient individual capabilities effectively. This investigation leads to the insight that joint action based on joint objectives or properties does not only increase the resource utilisation efficiency, but also reduces the interaction effort. Section 7.6.2 then addresses the interaction effort for team formation, an important prerequisite for adjusting the degree of autonomous control by joint action.

7.6.1 Interaction Effort for Resource Utilisation

For an autonomous logistics entity, choosing an appropriate partner for cooperation is constrained by the type of service required, by spatiotemporal criteria, and by free capacities as well as by the expected reliability of each service provider (Sect. 7.3.1). These aspects help narrow the set of potential cooperation partners from all logistics service providers to those that are actually able to fulfil the given demands.

However, the properties of autonomous logistics entities change over time caused by the dynamics of logistics processes. For instance, means of transport change their spatial position and may be loaded or empty. As another example, storage facilities have fluctuating utilisation rates. Therefore, finding a suitable service provider requires an autonomous entity to consider all potentially matching ones. The effort needed for effectively utilising resources in autonomous logistics is generally linear to the number of providers of a respective resource for each single logistics entity intending to utilise it. Consequently, the overall effort is equal to the number of service providers n times the number of service consumers m. The asymptotical complexity for resource utilisation is thus $O(nm) = O(n^2)$.

As the effort needed for resource utilisation depends directly on the number of interacting entities, that very number is the key determinant for an appropriate degree of autonomous control. If the required amount of interaction processes exceeds the computational gain achieved by problem decomposition, it renders the chosen degree of autonomy unsuitable. Yet, joint action of logistics entities pursuing equivalent objectives allows not only for efficient resource usage (Sect. 7.5), but also helps reduce the number of actually interacting participants. In a team of autonomous logistics entities, only one of them represents the whole team. Thus, the number of interacting entities is reduced by the ratio of entities to teams (Fig. 7.3). Hence, cooperation of autonomous entities with similar objectives allows for retaining the computational advantages of problem decomposition as well as the scalability of autonomous control in logistics.

In addition to the reduction of the interaction effort for effective resource usage, teams of logistics entities benefit from the collective experience of their individual members [14]. Exchanging memorised information about cooperation reliability (Sect. 7.4.2) allows for the fast emergence of effective interaction structures by deriving expectations from the team's accumulated observations. Thus, cooperation also increases the ability of autonomous entities to react to changing conditions by using shared expectations for reducing the number of observations necessary for each single entity.

As a preliminary conclusion, the appropriate degree for autonomous control depends on the reduction of computational effort on the one hand compared to the increase of interactions required for coordination on the other. The latter furthermore is determined by the total number of participating entities and the potential for joint pursuit of similar goals. Nevertheless, while cooperation helps confine the interaction effort and even improves the adaptivity of an autonomous logistics system, the formation of a team of entities itself requires further interaction. Therefore,

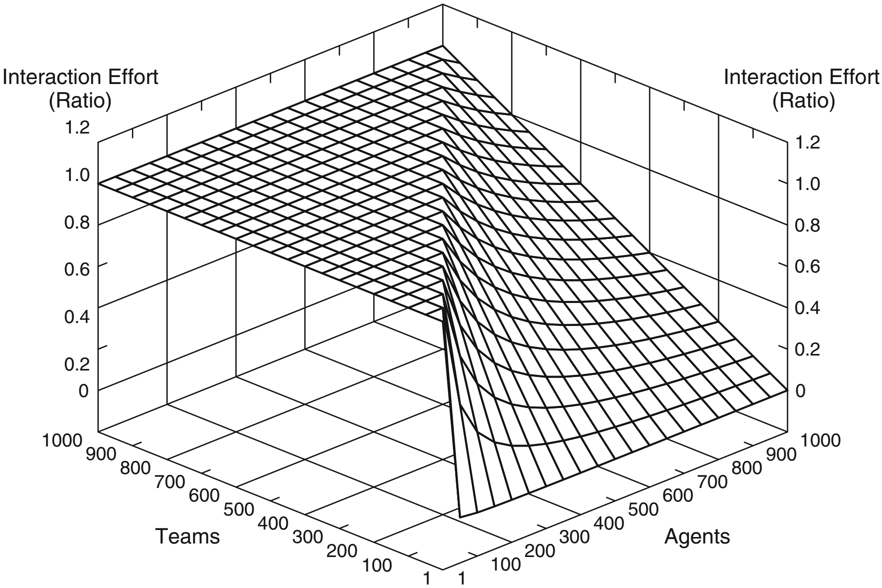

Fig. 7.3 The potential for decreasing the interaction effort for resource utilisation by cooperation. A high average number of entities per team leads to a low ratio of actually required interaction effort

the next section examines the complexity of team formation in order to facilitate determination of an appropriate degree of autonomous control in logistics.

7.6.2 Interaction Effort for Team Formation

Determining the interaction effort for team formation by directory is not trivial. In principle, each of the n participants in team formation has to contact all m team managers (Sect. 7.5.2). This means that the interaction complexity is $O(nm) = O(n^2)$. For most applications, however, it holds that $m \ll n$.

The actual interaction effort [27] depends not only on the pure amount of team managers and members. Instead, it also depends on the time at which participants become team managers. In the course of time, the number of team managers increases and therewith also the number of entities new participants have to coordinate with. Figure 7.4 depicts the total interaction effort for a scenario of $1,000$ entities which form between 1 and $1,000$ teams. The graph counts the total number of interactions until the appearance of the respective entity. The lowest interaction effort arises if only one team exists which is joined by all participants. The highest effort arises if every participant forms its own team.

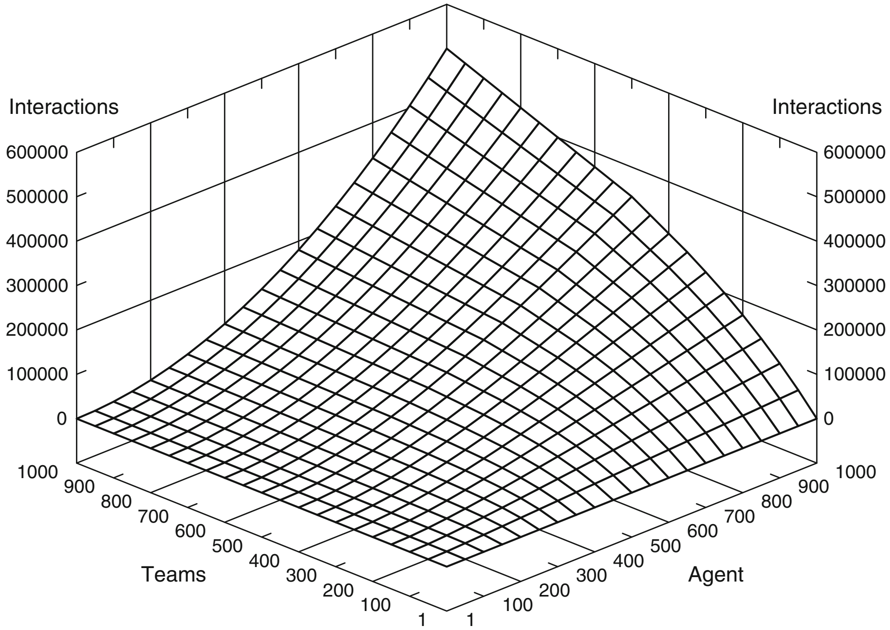

Fig. 7.4 The interaction effort for team formation of 1,000 entities based on a directory service. The interaction effort increases with the number of teams established

A limitation of the proposed team formation interaction protocol (Sect. 7.5.2) is reached when the interaction effort exceeds the capabilities of either the individual entities or the whole logistics system. Two alternatives exist for resolving this situation:

1. The number of participating entities can be restricted, e.g., based on spatial regions of relevance [9].
2. Instead of a directory, a broker can be employed, thereby decreasing both the degree of decentralisation and the interaction effort [25].

To summarise, team formation helps reduce the interaction effort for resource utilisation. It particularly enables choosing an appropriate degree at which autonomous control is applied. Team formation itself requires a certain interaction effort. This can be approached by carefully choosing both the participants and the interaction mechanisms.

7.7 Conclusion

Finding an appropriate degree at which autonomous control is applied is one of the key tasks in designing autonomous logistics processes. On the one hand, problem decomposition helps reduce the computational effort. On the other hand, the interaction effort increases with decentralisation because the participants must coordinate each other. Cooperation of autonomous logistics entities is thus an important foundation for autonomous control.

To narrow the optimal degree for autonomous control, the potential for cooperation in autonomous logistics is identified. Cooperation is a prerequisite for both *effective* resource allocation by matching complementing capabilities and *efficient* resource utilisation. Methods for implementing both occurrences of cooperation are presented. Apart from their potential, these methods are also examined regarding their limitations in order to derive an appropriate degree for autonomous control. It turns out that the interaction effort can usually be reduced by joint action. To this end, autonomous logistics entities should cooperate based on joint objectives or properties. However, team formation itself also induces interaction effort. Therefore, it is important to choose team formation mechanisms carefully based on the intended application.

References

1. Akyildiz IF, Su W, Sankarasubramaniam Y, Cayirci E (2002) Wireless sensor networks: a survey. Comput Network 38(4):393–422
2. Berndt JO (2011) Self-organizing supply networks: autonomous agent coordination based on expectations. In: ICAART 2011, INSTICC Press, Rome, Italy
3. Brauer W, Nickles M, Rovatsos M, Weiß G, Lorentzen KF (2002) Expectation-oriented analysis and design. In: AOSE 2001, Springer, Montreal, QC, Canada, pp 226–244
4. Collins J, Youngdahl B, Jamison S, Mobasher B, Gini M (1998) A market architecture for multi-agent contracting. In: Agents 1998, ACM Press, Saint Paul, MN, USA, pp 285–292
5. Dignum R, Dunin-Keplicz B, Verbrugge R (2000) Agent theory for team formation by dialogue. In: ATAL 2000, Springer, Boston, MA, USA, pp 150–166
6. Ferber J, Gutknecht O (1998) A meta-model for the analysis and design of organizations in multi-agent systems. In: ICMAS 1998, IEEE Computer Society, Paris, France, pp 128–135
7. Fischer K, Schillo M, Siekmann JH (2003) Holonic multiagent systems: a foundation for the organisation of multiagent systems. In: HoloMAS 2003, Springer, Prague, Czech Republic, pp 71–80
8. Fischer K, Florian M, Malsch T (eds) (2005) Socionics. Scalability of complex social systems. Springer, Heidelberg, Germany
9. Gehrke JD (2009) Evaluating situation awareness of autonomous systems. In: Madhavan R, Tunstel E, Messina E (eds) Performance evaluation and benchmarking of intelligent systems. Springer, Heidelberg, Germany, pp 93–111
10. Hannoun M, Boissier O, Sichman JS, Sayettat C (2000) MOISE: an organizational model for multi-agent systems. In: IBERAMIA-SBIA 2000, Springer, Atibaia, Brazil, pp 156–165
11. Heinzelman WR, Chandrakasan A, Balakrishnan H (2000) Energy-efficient communication protocol for wireless microsensor networks. In: HICSS 2000, IEEE Computer Society, Maui, Hawaii, vol 8, pp 8020–8029
12. Hülsmann M, Windt K (eds) (2007) Understanding autonomous cooperation and control in logistics. Springer, Heidelberg, Germany
13. Horling B, Lesser V (2005) A survey of multi-agent organizational paradigms. Knowl Eng Rev 19(4):281–316, URL http://mas.cs.umass.edu/paper/366
14. Langer H, Gehrke JD, Hammer J, Lorenz M, Timm IJ, Herzog O (2006) A framework for distributed knowledge management in autonomous logistic processes. Int J Knowl Base Intell Eng Syst 10(4):277–290

15. Luhmann N (1995) Social systems. Stanford University Press, Stanford
16. MacQueen J (1967) Some methods for classification and analysis of multivariate observations. In: 5th Berkeley Symposium on Mathematical Statistics and Probability, University of California Press, Berkeley, CA, USA, pp 281–296
17. Montgomery TA, Durfee EH (1993) Search reduction in hierarchical distributed problem solving. Group Decis Negot 2:301–317
18. Nickles M, Weiss G (2005) Multiagent systems without agents – mirror-holons for the compilation and enactment of communication structures. In: Fischer K, Florian M, Malsch T (eds) (2005) Socionics. Scalability of complex social systems. Springer, Heidelberg, Germany, pp 263–288
19. Nickles M, Rovatsos M, Weiss G (2005) Expectation-oriented modeling. Eng Appl Artif Intell 18(8):891–918, DOI DOI:10.1016/j.engappai.2005.05.002, URL http://www.sciencedirect.com/science/article/B6V2M-4GJK86T-1/2/74b3c8947f7310792c5a5cb3235a091d
20. Ogston E, Vassiliadis S (2001) Matchmaking among minimal agents without a facilitator. In: Agents 2001, ACM, Montreal, QC, Canada, pp 608–615
21. Rosenschein JS, Zlotkin G (1994) Rules of encounter: designing conventions for automated negotiation among computers. MIT, Cambridge, MA, USA
22. Sandholm TW (1999) Distributed rational decision making. In: Weiss G (ed) Multiagent systems. A modern approach to distributed artificial intelligence, MIT, Cambridge, MA, USA, pp 201–258
23. Schillo M, Spresny D (2005) Organization: the central concept for qualitative and quantitative scalability. In: Fischer K, Florian M, Malsch T (eds) (2005) Socionics. Scalability of complex social systems. Springer, Heidelberg, Germany, pp 84–103
24. Schillo M, Fischer K, Fley B, Florian M, Hillebrandt F, Spresny D (2004) FORM – A sociologically founded framework for designing self-organization of multiagent systems. In: RASTA 2002, Springer, Bologna, Italy, pp 156–175
25. Schuldt A (2009) Decentralisation and interaction efficiency in cooperating autonomous logistics processes. In: LDIC 2009, Springer, Bremen, Germany
26. Schuldt A (2010) Multiagent coordination enabling autonomous logistics. Doctoral dissertation, Universität Bremen, Germany
27. Schuldt A (2011) Team formation for agent cooperation in logistics: protocol design and complexity analysis. In: ICAART 2011, INSTICC Press, Rome, Italy
28. Schuldt A, Werner S (2007) Towards autonomous logistics: conceptual, spatial, and temporal criteria for container cooperation. In: LDIC 2007, Springer, Bremen, Germany, pp 311–319
29. Smith RG (1977) The contract net: a formalism for the control of distributed problem solving. In: IJCAI 1977, William Kaufmann, Cambridge, MA, USA, p 472
30. Timm IJ, Knirsch P, Kreowski HJ, Timm-Giel A (2007) Autonomy in software systems. In: Hülsmann M, Windt K (eds) (2007) Understanding autonomous cooperation and control in logistics. Springer, Heidelberg, Germany, pp 255–273
31. Windt K (2008) Ermittlung des angemessenen Selbststeuerungsgrades in der Logistik – Grenzen der Selbststeuerung. In: Nyhuis P (ed) Beiträge zu einer Theorie der Logistik, Springer, Heidelberg, Germany, pp 349–372
32. Windt K, Hülsmann M (2007) Changing paradigms in logistics. In: Hülsmann M, Windt K (eds) (2007) Understanding autonomous cooperation and control in logistics. Springer, Heidelberg, Germany, pp 1–16
33. Wooldridge M, Jennings NR (1995) Intelligent agents: theory and practice. Knowl Eng Rev 10(2):115–152
34. Wooldridge M, Jennings NR (1999) The cooperative problem solving process. J Logic Comput 9(4):563–592

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