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FLEXIBLE VWAP EXECUTIONS IN ELECTRONIC TRADING

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ABSTRACT

For the execution of large equity orders, institutional investors often use the Volume Weighted Average Price (VWAP) as a benchmark to measure execution quality. To achieve this, they have the possibility to either cross their orders in a non-intermediated electronic system or to submit a VWAP agency order to a broker that executes the orders manually. Though more expensive in explicit costs, agency VWAP is still more attractive to investors than VWAP crossings, in particular due to higher flexibility. This work proposes a new electronic crossing model addressing and solving the flexibility restrictions present in today's VWAP crossing.

Keywords

Financial Services, Design and Implementation, E-Business Models & Architectures, Auction.

INTRODUCTION

The size of institutional investors' orders can range up to several percent of the average daily volume. Trading such orders on today's electronic trading venues is subject to explicit as well as implicit transaction costs of trading, e.g. opportunity costs and market impact (Schwartz & Francioni, 2004) (Massimb & Phelps, 1994). The market impact results from the information carried by the orders and from the premium paid for liquidity provision.

In order to manage and minimize these costs, benchmarks are applied to measure execution performance and to be able to compare execution venues and the execution services of brokers. As of today, the most established benchmark is the Volume Weighted Average Price (VWAP) as it is easy to measure (sum of all trade prices x number of shares / number of shares over a respective period), easy to communicate and as it is provided from most information vendors (Reuters, Bloomberg, etc.) (Schwartz & Francioni, 2004). To achieve this benchmark, institutional investors either execute large orders without any broker intermediation within an electronic crossing system that imports the full day VWAP from a trading venue (reference market) or these orders are handed over to a broker that executes the order successively and manually in the markets applying data on market volume distributions. According to literature (Bialkowski et al 2006), VWAP orders represent around 50% of all institutional investors' trading.

We propose a conceptual market model for non-intermediated crossing sessions in a fully electronic environment, which provides anonymity and lifts the constraints of full-day VWAP by introducing the possibility of crossing investors' orders at forward intraday VWAPs

The existing trading model of non-intermediated VWAP crossing in electronic systems separates price and volume negotiations from each other, such that the size of the order has no market impact. The process starts by submitting an order into a closed order book before the reference market opens. Whenever there is quantity available at both sides, the orders are crossed within a session before the reference market opens and trades occur. After the reference market closes, the VWAP gets imported and the previous trades are enriched by setting this price. The strategy of trying to cross big orders in the first

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place before trading them in chunks over time has been shown to be cost effective (Naes & Skjeltorp, 2003). However, the long period between execution and price determination is subject to the risk of price movement, as the market can move into an unfavorable direction. Based on transaction costs in trading, the long period of one whole trading day leads to high opportunity risk.

The other option is an agency VWAP order, where the investor hands the order to a broker for execution bound to VWAP as benchmark. The broker splits the order into smaller chunks and executes them over time or even across multiple execution venues trying to achieve the VWAP benchmark. Although the agency VWAP is subject to transaction costs and principal-agent risk, it offers flexibility to the investor: First, the investor can specify a time period other than the whole trading day, for example the VWAP for several hours. Additionally, the order can be canceled during execution, for example if important news regarding the traded instrument occurs. Finally, the investor has the chance that his order is executed at a price better than the VWAP.

Given that the flexibility advantages of the agency VWAP trading are attractive to institutional investors (despite high explicit costs, i.e. brokerage fees), our new crossing model includes some comparable value proposition. It offers full flexibility relating to the time period of VWAP executions based on an order book market model.

The remainder of this paper is organized as follows: the next section will give an overview of the existent academic literature in the context of VWAP trading followed by a presentation of a forward VWAP trading model offering investors a high grade of flexibility in trading. Finally, the last section will conclude.

RELATED WORKS

In the academic literature, work on VWAP trading or crossing in general can be found, whereby most of the literature focuses on the investor's perspective, i.e. optimizing VWAP strategies or reducing transaction costs by the use of crossing networks. The design of mechanisms for VWAP trading from a market operator's perspective, i.e. the derivation of market models to satisfy investors' needs, can not be found in literature yet.

An extensive overview on the topic of VWAP trading from the investor's perspective is given e.g. by (Madhavan, 2002a). The meaning of transaction costs in general and the problem of implementing an - in theory - alpha generating portfolio investment strategy is presented for hedge funds in (Madhavan, 2002b).

By means of theoretical modeling a "static optimal execution strategy" of a VWAP trade is derived and proved appropriate with empirical data in (Konishi, 2002). Here, the optimal execution strategy is calculated by an iteration of a single variable optimization. It is shown that optimal execution times lag behind expected market trading volume distribution as price volatility has a positive correlation with market trading volume (Lamoureux & Lastrapes, 1990)(Lee & Rui, 2002). Essentially, execution error can be reduced by spreading out execution times according to the correlation of price movement. Another agency VWAP trading algorithm within a limit order book model is developed in (Kakade et al., 2004)

The costs of trading in crossing networks is highlighted in (Naes & Odegaard, 2005) by a comparison of effective trading costs and the costs of non-trading (when an order or a part of it could not be executed in a crossing network). By means of one institutional investor's data set they provide evidence that the low effective trading costs for crossing networks are offset by the costs of non-trading.

Against the background of best execution in institutional investor trading a discussion on the quality of benchmarks like VWAP or High-Low-Open-Close (HLOC) can be found in (Schwartz & Wood, 2003).

Two trading mechanisms for large-block trades are analyzed in (Madhavan & Cheng, 1997), namely the "downstairs" markets, such as NYSE floor, and the "upstairs" markets where counterparties to a trade are actively searched and prices are determined by negotiation in order to avoid adverse pricing by insufficient liquidity in the "downstairs" market. Those negotiations often rely on benchmarks like VWAP.

As stated in (Edelen & Kadlec, 2006), the evaluation of a trader's performance by portfolio managers is mainly based on a comparison of the price per share that the trader has reached and the VWAP during a whole trading day. It is empirically shown that this fact gives a trader some incentives which do not comply with the portfolio manager's objectives and thus fortifies the principal agent problem.

As already indicated, related research addresses various topics regarding VWAP and institutional investors' trading needs, but does not deal with a suitable VWAP crossing model itself. Therefore, the goal of this work is to extend existing research by presenting a new flexible model for forward VWAP crossing in a fully electronic environment, utilizing the benefits of crossing (Almgren & Lorenz, 2006)(Naes & Skjeltorp, 2003) and addressing the risk of price changes inherent to full-day crossing. Forward VWAP crossing relates to the fact that investors have a facility to submit their orders before the trading session - from which the VWAP is imported - starts. Consequently, the execution price is first unknown to the investor at the time of order submission and second not yet determined when the actual crossing of orders takes place. Thus, the model is different from "off-hours" VWAP crossing where investors have the opportunity to cross their orders after a regular trading session (off-hours) in which a daily VWAP or a VWAP for a certain period of time has been determined.

FLEXIBLE VWAP TRADING – THE MARKET DESIGN

This section presents a new model for crossing orders based on the VWAP. As transactions resulting within a crossing system are excluded from the price finding mechanisms implemented in the respective reference market the VWAP is not influenced by them.

General Market Model Characteristics

The model is investor order driven, that is, neither external market makers nor the provider of the platform supply liquidity or act as counterparty. Such a model is in-line with and shares the advantages of other crossing platforms as well as order driven trading venues.

The overall trading period is bound to the operating times of the reference market with the first crossing at the opening and the last crossing before the closing of the reference market.

The key idea of the proposed model is that crossings are triggered based on the start times (and end times) of the VWAP periods submitted by investors as order parameters. This provides full flexibility concerning the time windows in which the VWAP is determined and thereby differs from existing full day VWAP crossings. In the model, the submitted start times and end times for the VWAP calculations are displayed in an order book (see figure 1). Thereby, other investors can react to the order submissions and liquidity can concentrate at specific time windows, i.e. investors can join time periods already present rather than specifying new ones.

Besides the desired start and end times, the order book is closed in a way that neither volume nor market side information is shown in order to prevent market impact in the reference market. As a consequence, the order book presented in an investor's front-end is concentrated on the VWAP calculation periods of orders standing in the book. Additionally, it may be enhanced with information from the reference market (see figure 1). Trading is anonymous, so investors do not know each other in advance of the trade.

Order Book

Symbol	VWAP Start	VWAP End	Open	Close	High	Low
DE0007100000	10:00	10:30	69.00	68.42	69.12	67.81
	10:00	11:00	69.00	68.42	69.12	67.81
	10:00	12:00	69.00	68.42	69.12	67.81
	11:00	12:00	69.00	68.42	69.12	67.81
	13:00	15:00	69.00	68.42	69.12	67.81
DE0008404005	10:00	11:30	140.33	139.26	141.94	138.25
	10:15	11:45				

Figure 1. Order book snapshot at the front-end. Orders with five different VWAP calculation periods (e.g.10:00 - 10:30) are shown for the first instrument, enriched by reference market information: today's opening, high, low and yesterday's closing prices.

Trades are finally and fully confirmed at time of completion, including the trade price. This means that after a successful cross, the investors get a preliminary execution confirmation including the crossed size without price information. The final trade confirmation (including the execution price) is sent after the VWAP has been calculated, that is, after the specified period has passed. At this point, the trade price is available and will be reflected in the trade confirmation. In order to protect investors and as additional incentive, safeguards against extreme events and reference market movements are presented.

Market operators typically generate their revenues on a per transaction and/or crossed volume basis and thus benefit from more transactions and volume attracted by the system's flexibility. Further incentive for the system's users and operators is its ease of integration in existent infrastructure, e.g. multi-tier architectures already in use. Common message formats require either only new parameter values (e.g. start time, order type) or additional fields. The FIX Protocol, for instance, already has a comprehensive set of available parameters and allows for custom tags which have been used in the past to introduce new parameters. After adoption, the parameters were assigned to fixed tags in a future protocol version. The most effort emerges in the operator's back-end where the new model has to be implemented.

Order Types and Parameters

The key new parameters that are not yet implemented in other crossing systems constitute the start times and end times for the desired window for VWAP calculation. Based on this, we have designed several possible types of orders for the system developed in this paper. The first one is a 'plain vanilla' order named strict. This type carries the minimum parameters needed, namely buy/sell indication, quantity, start time and end time. At the time of order arrival within the system, the order entry time is attached to maintain time priority for the matching mechanism.

The strict order can be modified by parameters like "all or none" or "minimum execution quantity", further constraining the order. A strict order participates only in crossing auctions with exactly matching start and end times, and unexecuted quantity is deleted as in state of the art full day crossing systems.

An additional order type, "start fix", allows for partial period matches. Such orders can be executed against orders with the same start time but different end time (see figure 2). In order to enable the investor to achieve the VWAP, these orders' quantity available for crossing against different periods orders is adjusted according to the historical volume pattern. Details are depicted in the matching description.

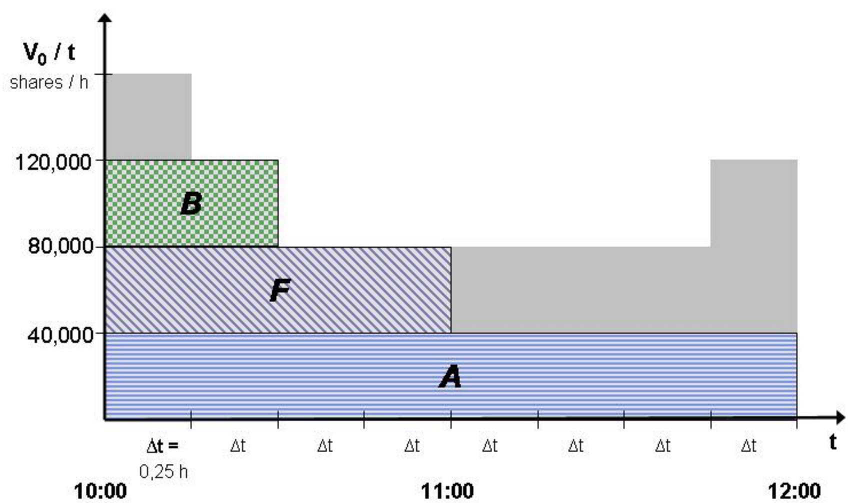
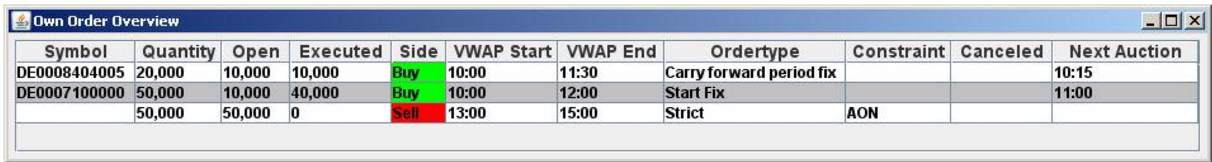


Figure 2. A graphical visualization of an order within a simplified non linear volume pattern, showing the quantity to execute in every Δt. Here, 110,000 shares have to be executed between 10:00 and 11:00, with 70,000 for 10:00 – 10:30. The capital letters correspond to periods applied in this paper's subsection about matching rules

Further order types are "carry forward" orders where unexecuted quantity is forwarded to the next crossing session. Two subtypes are possible, either "end fix" orders which can only be carried to sessions with a later start time but the same end time and "period fix" carried into sessions of exactly the same length. In the first case, quantity is again adjusted to the historic volume pattern, while in the second, the quantity remains unchanged. This "carry forward" order type represents a cancellation of remaining quantity (e.g. a strict order) and submission of a new one for a later period. As an incentive to use these orders, the time priority prevails. The benefit for the system is enhanced liquidity, as the trading interest remains within the system. While the carry forward orders are waiting for the start of the next auction, the unexecuted quantity can be canceled by an investor. The period fix version addresses investors who are not bound to the period of VWAP calculation and to timing of the order but focus on the average price. The carry forward orders can optionally have a maximum forward parameter, e.g. the latest start time. Parameters like 'all or none' are still applicable.

All orders submitted to the market, which have not yet been completely filled, will be kept in an investor's personal order overview. Besides information on an order's characteristics and status, that overview may contain an indication for the next crossing auction available for each order (see figure 3). Obviously, that information has to be broadcasted continuously by the system's back-end, as new orders with new periods can arrive changing next auction start time.



Symbol	Quantity	Open	Executed	Side	VWAP Start	VWAP End	Ordertype	Constraint	Canceled	Next Auction
DE0008404005	20,000	10,000	10,000	Buy	10:00	11:30	Carry forward period fix			10:15
DE0007100000	50,000	10,000	40,000	Buy	10:00	12:00	Start Fix			11:00
	50,000	50,000	0	Sell	13:00	15:00	Strict	AON		

Figure 3. Personal order overview for two different instruments at the investor's front-end. As for the first instrument, the carry forward order has been partially filled and will participate in the next auction corresponding to its parameters at 10:15.

Trading Phases

The phases are order entry phase, crossing auction, VWAP calculation period, price determination and confirmation (see figure 4). There is no fixed order entry phase; however, the first order submitted into the system sets an event driven time window between this first order entry time (t_0) and the specified VWAP calculation start time (t_1). The order book shows the submitted start and end times to enable other traders to join these VWAP calculation windows. Orders can be canceled before the start of the crossing auction.

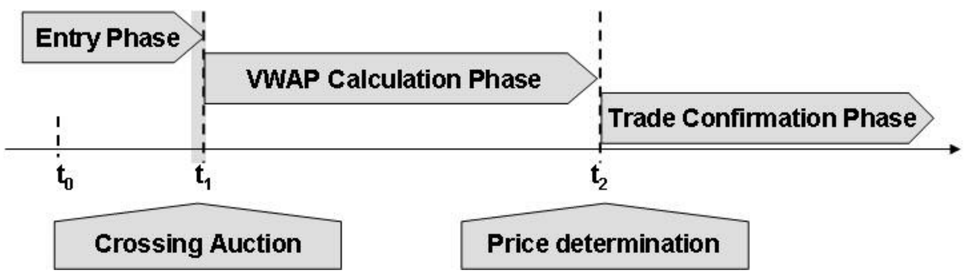


Figure 4. Trading phases.

The order entry time is important for the time priority as one factor for the matching mechanism. Immediately (e.g. 1 min.) before the start time t_1, a crossing auction occurs, matching orders based on the matching rules described below. Orders can not be withdrawn as soon as the auction starts. After the crossing, execution confirmations with the executed quantity are sent to investors. The execution confirmations have no counterparty information to prevent a black board effect where investors could submit only a small quantity to the crossing system and negotiate their real quantity bilaterally with counterparties disseminated through the confirmations. These investors already have shown their acceptance of the time period and would be potential counterparties for bigger trades, which could lead to lower liquidity in the actual system.

At the time the auction ends, the calculation period for the corresponding VWAP begins. The VWAP for the specified period will represent the price for the trades already crossed in the auction. The executed orders can not be withdrawn from the system by the investors. Additionally, after the crossing auctions end, at the beginning of the VWAP calculation, unexecuted quantity is handled. Remaining quantity for strict orders is deleted. Remaining quantity or unexecuted orders from carry forward types (either end fix or period fix) are waiting for the next suitable crossing session. If time constraints, e.g. VWAP end time, are reached, the remaining quantity is also deleted.

At t_2, the calculation of the VWAP ends and the price of the transactions is determined. This price allows for enrichment of the trade data completing the transaction.

After t_2, the trade confirmations are prepared and sent to the investors, including all data required for post trade processing. This includes data previously included in the execution confirmations as well as price and counterparty information. Together with confirmation of the trades, reports required by regulation are prepared and sent and the transactions are disseminated to the market.

Since investors are free to specify the time periods, these trading phases are present for every single period. This includes overlapping ones, which are relevant within the matching mechanism.

Matching Rules

Corresponding orders on opposite sides of the market are matched based on time period, entry time, calculation start time and volume maximization priority. Time priority of order entry rewards users which have revealed their preferred time period to the market. As the VWAP is imported from a reference market and set as the transaction price for all executed orders, there exists no price priority by design. However, every single crossing auction is a special case of a call auction (Economides & Schwartz, 1995) where every order has the limit price p* (VWAP for the given period), maximizing the traded volume.

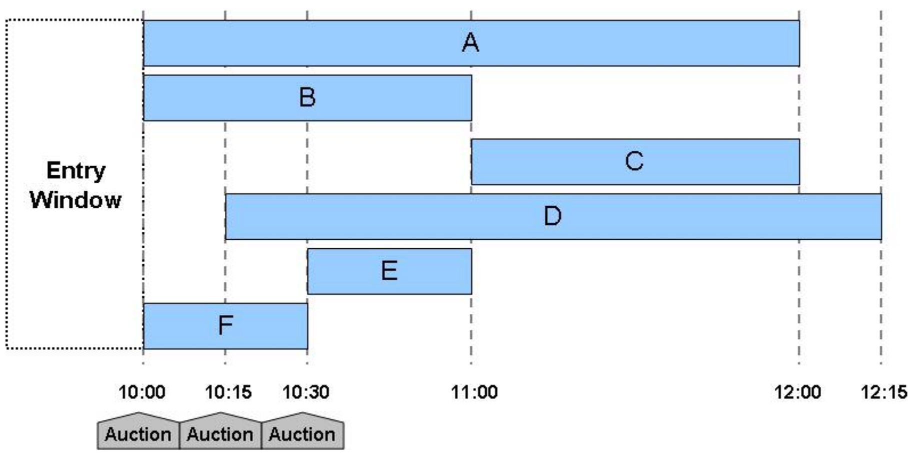


Figure 5. Various partially or fully overlapping time periods specified within submitted orders. In order to provide examples for the matching rules, the depicted points in time and periods are used below. Additionally, for the examples it is assumed that a crossing auction at 10:00 takes place.

Crossing auctions are triggered by the start time parameter of submitted orders. At t_1, all orders with exactly matching time periods - i.e. from t_1 (start time) to t_2 (end time, see figure 4) - are matched. This includes forwarded orders from previous auctions. In the example in figure 5, this would affect orders marked as A, with specified intervals between 10:00 and 12:00 where t_1 is 10:00. Additional, parallel auctions would occur at the same time (10:00) for orders depicted as B as well as for orders depicted as F. To this point, the crossing is comparable to existing full day VWAP crossing systems except for the flexible time interval.

Unexecuted orders as well as remaining quantities from partially executed orders marked for strict matching (order type) are deleted at the end of the auction. New is that whenever there is unexecuted quantity enabled for partial period matches (start fix) and which is residual from the first auctions at 10:00, additional auctions including different time periods but same start times are triggered. As an example, orders marked A and B would be included in an additional crossing auction. In order to enable investors to achieve an overall price as close to the VWAP as possible, remaining quantity of orders marked A in the example is scaled down reflecting the average volume traded in the shorter period (here B) in proportion of the average volume traded within the full period. Suppose the traded volume pattern between 10:00 – 12:00 is linear with time. Here, only one half (50%) of the remaining, previously unmatched quantity of a 10:00 – 12:00 order would be included to match a 10:00 – 11:00 order. By this mechanism, the investor is left 50% of the remaining quantity to either work the order through agency execution or to submit an order with the remaining quantity for another period (11:00 – 12:00) such that the aimed VWAP can be achieved. The investor is free to submit a carry forward end fix order into the crossing system within the entry time which would be automatically forwarded and keep time priority or to cancel the unexecuted quantity and submit additional orders into the crossing system for 11:00 – 12:00 (marked C in the example).

If there are several overlapping intervals with the same start time and unexecuted quantity (e.g. an additional interval 10:00 – 10:30, marked F) , the remaining quantity is readjusted and traverses the available auctions sequentially, starting with the longest interval in order to maximize matched quantity. Because quantity is adjusted based on historical volume, the longer the period the more shares can be submitted, which is beneficial to the investor. Scheduling auctions based on the benefit represents a greedy solution. Modeling an order on one side as a knapsack (quantity to be filled) and the corresponding orders as items to put in (as fills), we have a fractional (assuming orders are fractional) knapsack problem (Dantzig, 1957) where greedy delivers optimal solutions.

The quantities can be calculated by subtracting the quantity needed for uncovered periods first (e.g. 100,000 shares remaining – 50,000 for 11:00 – 12:00), then subtracting matched quantity after every auction (50,000 – 25,000 matched between 10:00 – 11:00) and calculating the fraction based on the historical volume pattern afterwards (25,000 left for 10:00 – 11:00 multiplied by 50% as the fraction of 10:00 – 10:30 in comparison to 10:00 – 11:00 based on the assumed linear volume pattern).

Afterwards, remaining, unmatched quantity is handled as described above. In the example, carry forward end fix orders would be carried to C (auction at 10:30), carry forward period fix orders would be carried to D.

The pseudo code for order handling at t_a (marginally before t_1) as well as the used data structures and functions (Table 1) can be seen below.

O_i, EO_j , UEO,	Sets of orders, EO for executed and UEO for unexecuted orders. A partial execution can be treated as a combination of an executed and an unexecuted order. The operations $O_i \setminus EO_j$ or $UEO \setminus EO_j$ will care of partial executions.
α_i , ω_i	Parameters containing the start (t_1) and the end times (t_2) of the VWAP calculation of the given order o_i
$P_i \in \{0,1\}$	Selection parameter, where 0 = strict and 1 = start fix order
match{S} S → EO	Function matching orders in the set S, returning executed orders EO. The outcome depends on the matching rule e.g. based on the submission time priority. Partial executions lead to an executed and an unexecuted order, $o_i \rightarrow o_{ie}$, o_{iu} where $volume(o_i) = volume(o_{ie}) + volume(o_{iu})$.
select{S, α, ω, P}	Returns a subset of the given order set S, where the parameters α, ω, P of the included orders match the specified variables. Unused parameters are specified by a wildcard *
adjust{S, a, w}	Returns a set of adjusted orders with rescaled volume
endtimes{S, α, w}	Returns an ordered set (latest first) of all end times from orders with start time α and optional with end times before w (t < w) in the given set S.
carryforward{S, α}	Adjusts carry forward orders with originally earlier start times for auction at time α in set S, setting new start time and rewriting the volume (carry forward end fix)

Table 1. Data structures, parameters, functions and procedures

```
EOt := Ø, UEO := Ω
        (At the beginning, all orders are unexecuted)
At ta (marginally before t1)
        carryforward{UEO, t1}
                (Forward unexecuted 'carry forward' orders if existent from earlier auctions to the current auction)
        for t in endtimes{UEO, t1, *}:
                (Select all end times of orders with start time t1 , e.g. 10:00)
                O1      := select{UEO, t1, t, *}
                (Select orders for auction with exactly corresponding time periods t1 - t, e.g. 10:00 – 12:00)
                EOt     := match{O1}
                UEO     := UEO \ EOt
                (New unexecuted order set, reduced by the set of executed orders)
        end for
        for t in endtimes{UEO, t1, *}:
                (Select all remaining available endtimes)
                O2      := select{UEO, t1, t, 1}
                (Select previously unexecuted or partially executed start fix orders, e.g. 10:00 – 12:00)
                for z in endtimes{UEO, t1, t}:
                        (Select all endtimes before t, e.g. 11:30 if t is 12:00)
                        O3      := adjust{O2, t1, z}
                        (Orders originally designated for the longer period, e.g. 10:00 - 12:00 need a volume
                        adjustment)
                        O4      := select{UEO, t1, z, 1}
                        (Select start fix orders for the shorter period, e.g. 10:00 – 11:30)
                        EOz     := match{O3 U O4}
                        (Match both the adjusted orders and the orders for a shorter VWAP period)
                        UEO     := UEO \ EOz
                        O2      := O2 \ EOz
                        (Remove executed orders from all unexecuted and from subset O2. Remainder of O2 will
                        be further matched against shorter VWAP period orders, e.g. 10:00 – 11:00)
                end for
        end for
```

Safeguarding

The risk for the individual trader/investor concerning the forward crossing mechanisms results from the fact that an order is crossed before a respective price is determined. Because of this setup, investors cannot cancel their orders during unusual market conditions, e.g. periods of high volatility caused e.g. by ad-hoc news for a security. Agency VWAP orders that are executed by brokers have such a cancel option, but by design only for the remaining, unexecuted quantity. A crossing design has the potential to offer higher investor protection. In a full day VWAP cross, for example, late information disseminated to the market, which will lead e.g. to a higher opening price the next trading day, leaves investors on one side of the cross with an unfavorable price. To overcome this risk, ITG offers safeguards for their after hour crossing sessions by monitoring late news and the possibility to cancel a crossing session. Although the probability of unfavorable news during a crossing session is higher for longer rather than shorter sessions, the impact of positive or negative news on a short-term VWAP might be even greater, leaving an investor with potential price risk and no possibility to react. For this reason, it is necessary to secure also short VWAP sessions with safeguard mechanisms to protect investors' interests. As a consequence, a crossing session in a particular security is canceled and all orders returned to the investors unexecuted, if price jumps in the reference market exceed a certain limit upwards or downwards and thus the volatility in that security becomes too high. That limit can be set as a percentage deviation from the reference market's last price at the beginning of the crossing session and is not disclosed to the investors to avoid manipulation. For the same purpose the percentage should not be set too low as an investor might "cancel" an order submitted to a crossing session by inducing price movements in the reference market and thus stop the entire session otherwise.

CONCLUSIONS

In order to have their orders executed at the VWAP, investors can submit a VWAP agency order to a broker or make use of a fully electronic crossing facility. Existing VWAP crossing facilities are characterized by low costs, but also inflexibility and price risk as the full-day VWAP is applied for crossing sessions. Based on this, a model with flexible VWAP sessions concerning start time, end time and time period appears necessary and in the investors' interest.

We proposed a conceptual market model for non-intermediated crossing sessions in a fully electronic environment, which provides anonymity and lifts the constraints of full-day VWAP by introducing the possibility of crossing investors' orders at forward intraday VWAPs. This model is based on an order book of start and end times for the VWAP periods that are specified by the users of the system, i.e. institutional investors. Thereby it offers – like brokerage agency orders – the opportunity to execute at flexible VWAPs. Investors may specify their orders as "carry forward" to make unexecuted quantity from one crossing session participate in the next session and thus increase execution probability. Besides, orders can be combined with restrictions like "all or none" or "minimum execution quantity". Corresponding orders will be matched based on time period, entry time and calculation start time priority. For investor protection the trading model features safeguards which will cancel a session in case of heavy price movements induced by unusual circumstances.

The next step in the project will be a systematic discussion of the model with potential users and – if positively evaluated – a development of a prototype of the proposed model that can be further analyzed e.g. by means of experiments.

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